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Preface

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The geological history of Saskatchewan is like a giant book, waiting to be opened and read. Unlike other volumes of earth history, which have been crumpled and torn by geological forces, the pages of the Saskatchewan book are relatively smooth, very little torn, and hardly at all affected by heat (volcanic activity). Although some pages, and even chapters, may be missing, it is a straightforward and legible record. But opening and reading this record has not been a continuous process.

Progress has been intermittent and irregular, influenced by historic events and the needs of people. This is well illustrated by the geological exploration of the southwestern plains portion of the province. The area was first studied and interpreted geologically by George Mercer Dawson as geologist with the British North American Boundary Commission survey of 1873 and 1874 (Dawson, 1875). He mapped the rock formations adjacent to the 49th parallel of latitude, and established the sequence of the strata and the record that they represented.

Among other achievements, Dawson was the first to find dinosaur fossils in Canada, in the badlands west of Killdeer.

The coming of railways and of the land survey led to the settlement of the Saskatchewan plains, and with it the exploitation of coal and clay deposits. In support of these developments the Geological Survey of Canada sent out Bruce Rose in 1913 and 1914 to map the geology and coal resources of the areas adjacent to Willow Bunch and Wood Mountain. Rose (1916) confirmed the geological observations of Dawson, but correlated his findings more closely with those of the American geologists working in North Dakota and Montana.

Regional geological mapping of southwestern Saskatchewan was resumed in 1927 and continued until 1931 by F.H. McLearn of the Geological Survey of Canada. The project was extended farther north by P.S. Warren in 1928 to 1930, and it culminated in the publication of the Regina Sheet (G.S.C. Map 267A) and of the memoir "Geology of Southern Saskatchewan" (Fraser, McLearn, Russell, Warren, and Wickenden, 1935). These publications are basic to the geological interpretation of the Saskatchewan plains.

Important fossil discoveries in this region go back to R.G. McConnell of the Geological Survey of Canada, who in 1883 found mammalian remains

in the Cypress Hills Formation (McConnell, 1885). His findings, and those of T.C. Weston, were reported by E.D. Cope (1891). Later collections were made by L.M. Lambe (1908), Fenley Hunter, L.S. Russell, and B.A. McCorquodale.

Russell published a number of reports on this fauna (1934, 1940, 1972). It is now recognized to be of Early Oligocene age.

C.M. Sternberg of the Geological Survey of Canada relocated and collected from the dinosaur-bearing Frenchman Formation of the Killdeer badlands and Frenchman River Valley, and was able to show (Sternberg, 1924) that the fauna correlated with that of the Lance Formation of Wyoming, the last of the Cretaceous dinosaur faunas of North America. Sternberg also discovered the Miocene vertebrate fauna of the Wood Mountain Gravel (Sternberg, 1930), thus showing that there was more than one age of deposition of plateau gravels in southern Saskatchewan. This was further demonstrated by the discovery by R.T.D. Wickenden in 1930 of Upper Eocene mammals in gravels near Swift Current. The fauna of these Swift Current Creek beds was described by Russell (Russell and Wickenden, 1933; Russell, 1965) and by Storer (1984).

Intermittent but large-scale collecting in the Wood Mountain gravel by Russell and Storer from 1968 to 1970 provided the basis for a monographic study by Storer (1975) on the mammalian fauna, and resulted in a dating of Middle Miocene. More recent discoveries of fossil mammals in the plateau gravels have established that there are at least seven mammalian faunas represented, ranging in age from Late Eocene to Middle Miocene.

An earlier chapter in the geological history of southwestern Saskatchewan is represented by the Ravenscrag Formation. It has long been recognized as the Canadian extension of the Fort Union Group of Montana. A detailed study of the fossil molluscs (Russell, 1974) indicated a Paleocene age, and this was confirmed by the discovery of an Early Paleocene mammal (*Carcinodon*) at the Pine Cree Park locality (Russell, 1974). This, and the discovery of Late Paleocene mammals in the Ravenscrag beds of southeastern Saskatchewan (Krause, 1977), show that the formation represents almost the entire span of Paleocene time.

Similar accounts could be written of the steps through which the geological record of other parts of Saskatchewan have been reconstructed. A three-dimensional synthesis of the results is offered in the Earth Sciences Gallery of the Saskatchewan Museum of Natural History. It is hoped that the viewer will gain not only an understanding of the geological history of the province, but also an appreciation of the work of dedicated researchers who have assembled and interpreted the data on which this impressive synthesis is based.

Introduction

Saskatchewan's ancient land life and environment — more than 2500 million years of changing landscapes and life created Saskatchewan's modern environment. Rocks and fossils tell the story.

Saskatchewan bears a wealth of natural resources and a diverse landscape. The province is noted for its rich soils, and its southern plains include some of the most productive farmland in Canada. Potash, found in deep beds beneath the southern plains, has assumed major economic importance, while oil and gas fields continue to produce in the southeastern and western parts of the province. Gold, base metals, and uranium found in northern Saskatchewan are vital resources. The scenic plateaux and grainlands of the south contrast sharply with the myriad lakes and forests of the north but all draw tourists from far and near.

This rich and complex landscape is the product of 3100 million years of development that we know of, and 1500 million years of history that remains undiscovered.

The Earth Sciences Gallery at the Saskatchewan Museum of Natural History is designed to help visitors look at our land, fossils, and mineral resources differently than before. Each part of the gallery is a chapter in our geological history, and each part can be a starting point for discovery of the past.

In the gallery, and in this book, we look at Saskatchewan's geological evolution as having passed through five major stages, leading to the present day. Not only does our geological history provide a framework for understanding Saskatchewan's life, landscape, and resources, but it also exemplifies the development of much of the Great Plains of North America.

First, two huge sections of continental plate separated, then by 1875 million years ago collided to form first a series of volcanic islands, then a range of mountains. By 1700 million years ago these mountains were eroding away into the shallow, tropical seas that covered much of the continent.

Shallow seas covered our area for much of the time from 1700 million years to 65 million years ago. At first, these seas were equatorial, then much later, in the Age of Dinosaurs when our continent was nearly in its present position, the seas were temperate and muddy-bottomed.

The seas retreated in the late Age of Dinosaurs, leaving the land and dense forests where the dinosaurs lived and, about 65 million years ago, became extinct.

From 50 million years ago to the beginnings of the Ice Age about two million years ago, our area underwent a major change in climate, and the ancient forests gave way to grassland.

At least five continent-wide glaciers advanced across Saskatchewan, and melted away. Humans came to North America while ice still covered much of what is now Canada. Finally, thousands of years after the last glaciation, the prairie originated.

Thus our present landscape and environment result from a series of geological events, some of them very far in the past. Each of our past environments has its own story. For each detail we know, there are many waiting for discovery. In many ways, the study of Saskatchewan's past is just beginning.

When exploring Saskatchewan for evidence of the past, please respect people's land, whether it is owned or leased, and follow the Saskatchewan Heritage Property Act, which places restrictions on the collecting of fossil vertebrates and archaeological material. Amateur collectors make many important finds and add life and interest to otherwise obscure studies, but unfortunately they may destroy material too. Museums are good places to get advice and help.

CHAPTER 1

Geology: The study of Earth

To interpret the significance of rocks and fossils, it is necessary to know something about the materials the earth is made of, the structure of the earth, the movements of the earth's crust, and the nature of geological time.

So that as much space as possible was available to show Saskatchewan's geological development, and the series of environments that led to the present day, introductory displays were kept to a minimum. These exhibits center on the dynamic forces within the earth that act to change our environment, either slowly and gradually or rapidly and violently.

The rock cycle. Rocks are constantly created, altered, and destroyed. A rock's characteristics indicate the conditions of its origin.

Rocks and Minerals, the Earth's Building Blocks

Rocks and minerals make up the earth's substance. Minerals are the basic building blocks (e.g., quartz, feldspar, mica) that combine to form rocks (e.g., granite).

Rocks and minerals are constantly being formed and destroyed, altered and combined. The **rock cycle** constantly operates, and by examining a rock or mineral we can usually find out how it was formed, and what part of the rock cycle is responsible for its existence.

Except for some cosmic debris that enters the atmosphere from elsewhere, all the earth's materials ultimately owe their origins to the flow of molten material (**magma**) from deep within the earth. Although the mantle (the molten area immediately beneath the continents and ocean basins) is composed mainly of silicon, iron, and magnesium, all the earth's elements occur there in greater or smaller concentrations. When this magma rises into cracks in the crust, it cools to form new rocks (**igneous** rocks) and adds to the volume of the crust.

The first rocks that formed on the earth's crust were igneous.

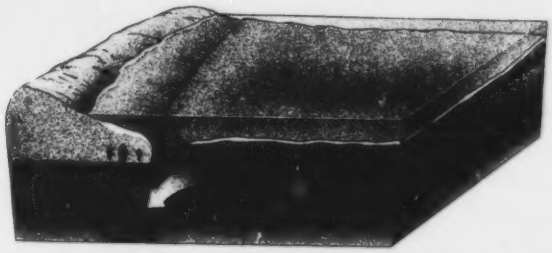
When the earth first formed 4600 million years ago from smaller particles, it was solid but undifferentiated. Gravitational forces, and possibly the impact of a Mars-sized body that hurled the moon into orbit, were sufficient to make it completely molten, and iron and nickel migrated inward to form the core.

Lighter elements flowed outward toward the surface. At this time no rocks existed on the earth's surface. Over the next few hundred million years, the earth cooled to the point at which its surface hardened in the same way ice forms at the surface of a body of water as it cools. By about 4000 million years ago, the earth's first rocks formed, and the earliest known rocks (in Africa) are 3825 million years old.

Molten material from inside the earth may rise to the surface or may fail to break through cooler, solid rocks and may harden underground. Generally speaking, the **volcanic** (or **extrusive**) rocks formed at the surface cool quickly and have small crystals, and **intrusive** rocks, formed below ground, cool slowly and have large crystals.

Igneous rocks fall into two classes: the heavy, dark-colored ones made of elements including iron and magnesium, and the less heavy, light-colored ones made of elements such as sodium and potassium. Heavy, dark volcanic rocks include basalt, which is very common on the earth's surface, and dark intrusives include gabbro. Light volcanics include rhyolite, a rock type usually produced in the latter stages of volcanic activity, and light intrusives include granite.

The distinction between heavy and light igneous rocks has had great importance in the earth's history. Areas of crust in which dark, heavy basalts and gabbros predominate are regions that sink deeper into the mantle and form ocean basins, while the continents, whose cores are predominantly made up of less dense rocks like granite and rhyolite, float higher. Ocean crust thus tends to be pulled downward more strongly than continental crust, and is more easily drawn



Oceanic crust is denser than continental crust, and normally sinks downward at plate edges. Continental crust floats higher, and is usually much thicker.

beneath lighter crust and destroyed. The marked difference in density between dark, heavy basalts and gabbros and light, less dense granites and rhyolites may have played a major role in the first plate movements in the primordial earth: perhaps the heavier rocks, riding lower and subducting under the lighter ones, determined the locations of the first plate boundaries. Then began the crust's evolution from a newly-cooled layer of uniform thickness to its present condition, with relatively permanent, thick continental landmasses and thin oceanic plates whose rocks are completely recycled every 200 million years or so.

Rocks exposed at the surface are eventually destroyed by the forces of nature, especially by the flow of water, in a process called **erosion**. Erosion mainly causes rocks to break up so that flowing water can carry the resulting particles downstream, but to a lesser extent erosion also dissolves particles of rock. **Sedimentary** rocks form where these particles and dissolved minerals come to rest.

In the deposition of **clastic** sediments (those made up of broken bits of rock), the coarsest and least rounded fragments almost always end up nearest the source area, i.e., the area from which the fragments were weathered. Harder minerals (quartz, for example) also survive extensive transport, while softer ones (e.g., feldspar) are likely to be destroyed quickly.

The distance a particle is carried depends upon its size, and upon the speed of the stream carrying it. Fast mountain streams can carry more and larger particles than slower streams on flatter surfaces like the plains. This is why we find few rocks forming in the mountains: in fact, mountain streams are almost always cutting into the older rocks rather than depositing new ones. On the

Erosion dominates in steep, mountainous areas, while deposition occurs in slower-flowing streams, lakes and oceans. Deposits laid down farther from the source area are generally made up of smaller grains.

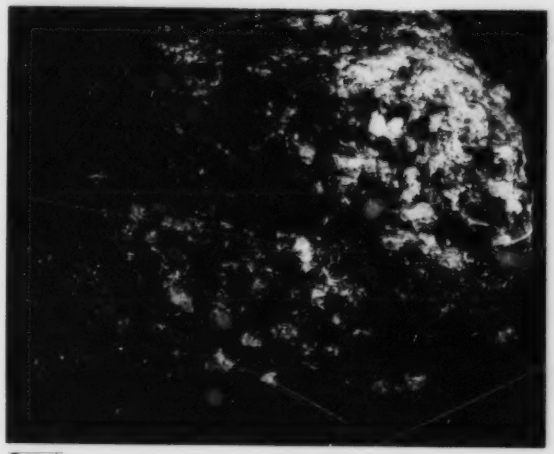
other hand, slower streams away from the mountains lay down many new deposits, and some become clogged with sediment. The finest, lightest particles may be carried all the way to the oceans, where they are deposited in river deltas, or at the bottom of the sea.

Therefore the geologist can examine a clastic rock and tell a lot about its origins from the size and roundness of its particles, and the minerals that make it up.

Some exceptions to the rule are windblown dust (loess) and sand, and rocks left behind by glaciers. In these cases, special clues are contained in the rocks, like the lack of bedding planes, or depositional layers, in loess and the scratches and isolation from similar rocks of glacial erratics that have been carried great distances by ice sheets.

Dissolved minerals are also deposited, as **chemical** sediments. Not only do dissolved substances fill spaces (e.g., dripstone, travertine) and form crystals (e.g., geodes) underground, they replace more soluble buried substances. For example, silica and other minerals dissolved in groundwater replace buried wood or bone, causing a fossil to be preserved.

In our gallery we see another example of chemical deposition, the salt, anhydrite, and potash beds of the mid-Devonian. In an ocean basin where deep currents were restricted, concentrations of mineral



Potash

salts gradually increased until crystals began to form at the bottom. Vast quantities of material precipitated out in this manner in the same way that salt or sugar crystals will form in a glass as a saturated solution evaporates.

By far the most important chemical sedimentary rock is limestone. Limestone may be made up partially of precipitated calcium carbonate (the material that makes up cement), but most of its substance is comprised of fossils. These fossils, whether whole or fragmentary, are the remains of plants and animals that extract calcium carbonate

from water to make their shells or other hard parts. The main life forms involved are calcareous algae and cyanobacteria, bryozoans ('moss animals'), corals, brachiopods ('lampshells'), and shellfish including clams, snails, and squid-like cephalopods. The plants and animals that make rocks in this way have been vital in the formation of our landscape: the limestones that hold their remains are nearly everywhere, and the ocean's reefs and carbonate banks are tomorrow's limestones. Limestones form mainly in the oceans, giving a valuable clue for interpreting ancient rocks, but freshwater limestones are known.

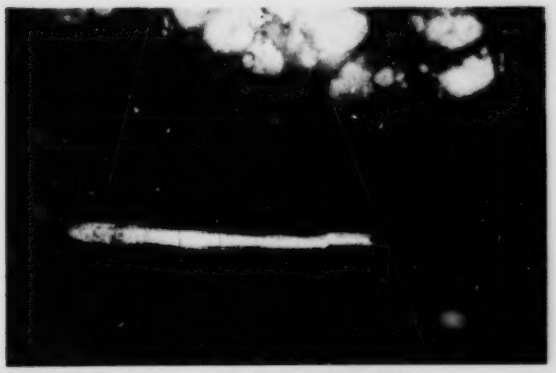
Both igneous and sedimentary rocks can be changed by heat and pressure, and the resulting rocks, with different minerals and structures than the originals, are called **metamorphic** rocks.

Metamorphism commonly takes place in zones of intense folding and mountain-building, or near large, hot masses of intrusive magma.

Metamorphic rocks are often layered, or banded. This banding may be caused by the alignment of platy minerals like mica in **low-grade** metamorphics like schist or slate that have been buried only shallowly. Or, in **high-grade** metamorphics like gneiss, which have been buried deeply and subjected to partial melting, bands may be made up of easily-melted minerals (like feldspar) and less easily-melted minerals (like hornblende). While igneous rocks are sometimes banded, revealing flow structures, and sedimentary rocks usually show bedding structures, the more ordered organization of metamorphic rocks usually gives them a different appearance than igneous rocks, and their greater hardness generally distinguishes them from sedimentary rocks.

A special, commonly seen, high-grade metamorphic rock is marble. Marble is an altered limestone, made up of recrystallized grains of calcite or dolomite. Because the crystals form easily and quickly, marble often does not show the bands characteristic of other metamorphic rocks. Elements that were present as impurities in the limestone may combine to form new minerals, which may merely give color to the marble, or may give it a striped, spotted, or cloudy appearance.

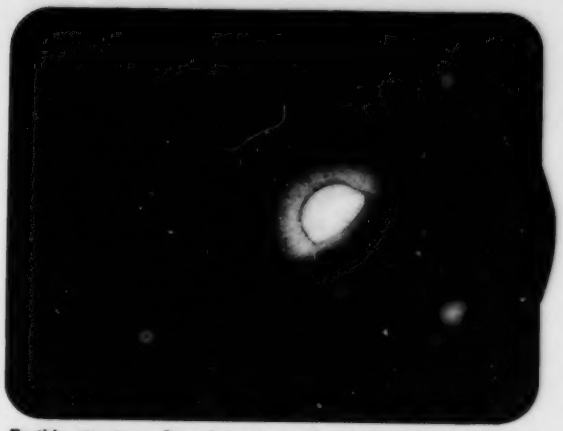
Marble that is only partly recrystallized may show the remains of fossils. An immediate example of this less thoroughly metamorphosed marble is the red, northern Italian 'Rosa Verona' in the Saskatchewan Museum of Natural History's lobby. A close inspection shows abundant algae and occasional belemnites and ammonoids, both of which are cephalopod molluscs, distant relatives of the squid and octopus.



Belemnite in Jurassic marble from northern Italy.

Ammonoid in Jurassic marble from northern Italy.

The Structure of the Earth



Earth's structure. Our planet is made up of a core, surrounded by the mantle, which is in turn covered by the crust on which we live. (display photo)

The earth is made up of layers called the **core**, **mantle**, and **crust**. We, along with all other living things, inhabit the crust, or **lithosphere**, which makes up the outermost six to 60 kilometres of the planet. The crust is quite thick by our standards; the recent United States 'Mohole' drilling program failed to penetrate through it to the moho (or Mohorovicic Discontinuity), and a current Soviet project has drilled nearly 12 kilometres without reaching the limit of the crust. But if the earth were the size of an apple, its crust would be only as thick as the apple's skin, and on a one-dimensional illustration of any convenient size the crust appears as a line. On the three-dimensional 1.28 metre diameter model in the gallery, the crust is one to five millimetres thick.

Our model is a one to 10 million scale model of the globe. A quarter of the globe is cut away, from the Arctic Circle to the Antarctic Circle. On the edge of the cut is Regina, and the section passes through two spreading ridges (the Nansen Ridge and Southeast Indian Ocean Ridge), a transform fault connecting two spreading ridges (the San Andreas Fault), and a subduction zone (the Mariana Trench).

The solid crust floats on an underlying, partly molten layer, called the **asthenosphere**. The asthenosphere is the uppermost part of the mantle, and is a transition zone into which subducted edges of crustal plates melt, and from which molten magma rises to form new crust.

The remainder of the mantle is somewhat more molten than the asthenosphere, and extends to 2889 kilometres beneath the surface. A drive from Regina to Washington, D.C. would cover a similar distance. The mantle is rich in iron, magnesium, and silicon, though its silicon concentration is somewhat less than that of the crust. Below the mantle lies the **core**.

Geophysicists separate the core into the **inner core**, which is solid and is composed mainly of iron and nickel, and the **outer core**, which flows as easily as water and is made up of liquid iron and sulphur. Near the core-mantle boundary it appears that there are irregularities in density and composition that may create differences in height of up to eight kilometres. Whether these displacements are like waves at the outer edge of the core, or perhaps represent continent-sized blobs at the core-mantle boundary, is as yet unknown.

The Earth's Dynamics: Continental Drift

The earth's crust, or lithosphere, is broken into six large plates and about 12 smaller ones. Because these plates float on the semi-molten asthenosphere, or upper mantle, they are able to collide with each other or separate from one another. In either event, the positions of the ocean basins and continents constantly change.

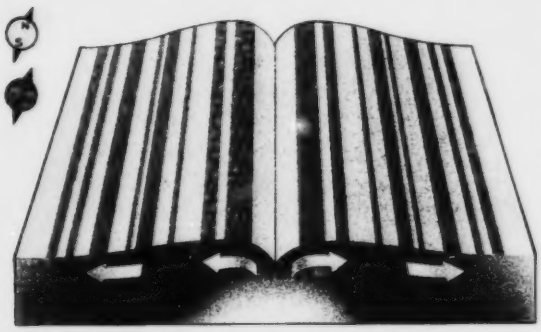
There is abundant evidence that the continents have indeed changed position during geological history. Some continental margins fit together extremely well, for example the Atlantic margins of South America and Africa. As early as the end of the nineteenth century, some geologists hypothesized that these continents had drifted apart in ancient times, opening the South Atlantic between them. There are also similar fossils, belts of mineral deposits, and evidences of an ancient glaciation, that appear to unite these continents plus Antarctica, Australia, and India into a single land mass called Gondwanaland, named after the Gonds, an ancient people of India.

More recently, however, the discovery and explanation of sea floor spreading ridges where molten rock can actually be seen oozing out onto the sea floor, and measurement of crustal spreading in Iceland has shown that the crustal plates do actually move, and can be presumed to have done so throughout time.

Moreover, geologists began to measure the magnetic orientation of the minerals that make up rocks. When very small particles of sediment come to rest, they align with the earth's magnetic field and gain a slight magnetic charge. Moreover, when rocks containing magnetic minerals are heated above a certain temperature they lose their former magnetism, and when they cool they gain a new magnetic orientation that aligns with the earth's magnetic field. By measuring the magnetic 'signatures' of rocks representing various parts of geological time, scientists could determine the past orientations of the continents to the earth's magnetic poles. But the evidence that was

gathered from different parts of the world made sense only if the continents had occupied different positions relative to each other.

The earth's magnetic field also reverses occasionally: for major segments of geological time the north-seeking pole of a compass needle would have pointed toward the earth's present south pole instead. These magnetic reversals not only help geologists to 'tell time,' because rocks of the same age have the same 'normal' or 'reversed' magnetic polarity; but also the symmetrically striped pattern of paleomagnetic polarities on either side of the Mid-Atlantic Ridge was an early clue to the ocean's spreading.



Paleomagnetic banding. Rocks with 'normal' and 'reversed' paleomagnetic orientations make a mirror-image pattern on either side of a spreading ridge.

Rocks that were formed 700,000 to 1.5 million years ago, with 'reversed' polarity, lie an equal distance from the Mid-Atlantic Ridge, and younger rocks with 'normal' polarity fill the area closer to the ridge. Outside the rocks with 'reversed' polarity are yet older, 'normal' deposits, and the pattern continues throughout the ocean basin's width. This paleomagnetic pattern suggests that rocks which originally formed at the Mid-Atlantic Ridge are being pulled gradually away from the ridge as new deposits fill the gap. This evidence led geologists to search for more clues, and put the theory of plate tectonics on a firmer footing than it had enjoyed before.

There are six major crustal plates today: American, Eurasian, African, Indian, Pacific, and Antarctic. About a dozen minor plates are also present. The African Plate appears to be the most stable of these: the others have moved more extensively during geological time, and most of them are made up of smaller fragments that have coalesced during the past fifty million years.

All plate boundaries are curved, and thus mid-ocean ridges and collision zones between continents have characteristic arc shapes. This occurs simply because of the earth's curvature. Any straight line on the surface of the spherical earth must be expressed as a curve on a map, except for a line exactly in the center of the projection.

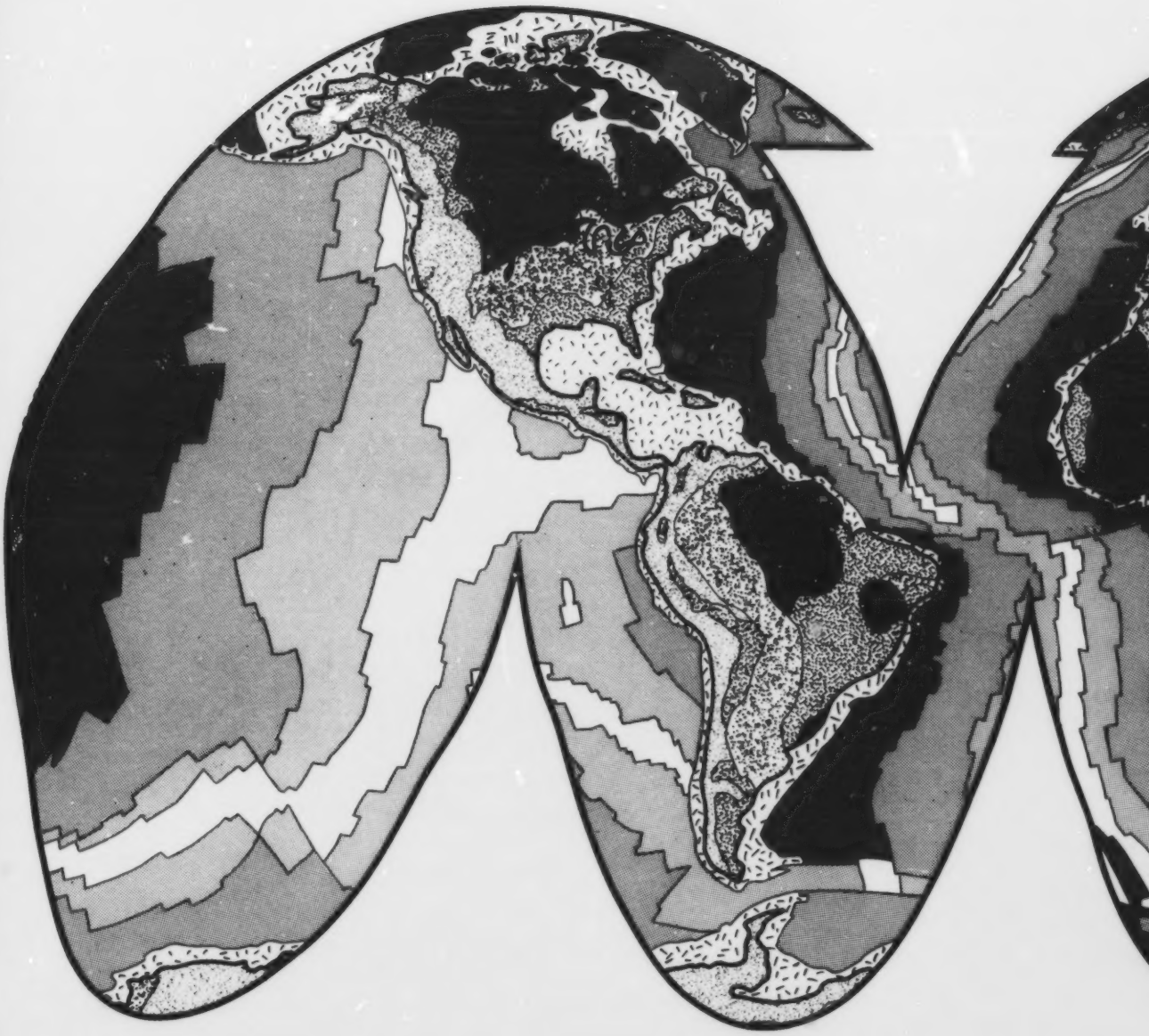
If crustal plates can grow and separate at mid-ocean ridges, then what happens when they collide elsewhere? On a globe of unchanging size, plates moving away from each other must push against other plates. We find part of the answer in the relative densities of plates.

For many years before the acceptance of continental drift, it was known that the continents were made of less dense rocks than the ocean basins, and that the continents were thicker, standing high at mountain ranges and extending deep down into the mantle, while the rock of the ocean basins was relatively thin. Thus the continents float higher on the mantle than the ocean basins. The principle of **isostasy**, which states that parts of the earth's crust seek their own levels depending on their densities, accounts, for example, for the rise in altitude of Scandinavia and northern North America since the Ice Age: with the melting of the glaciers, a huge weight was taken off the crust in those areas, and they have been 'rebounding' ever since.

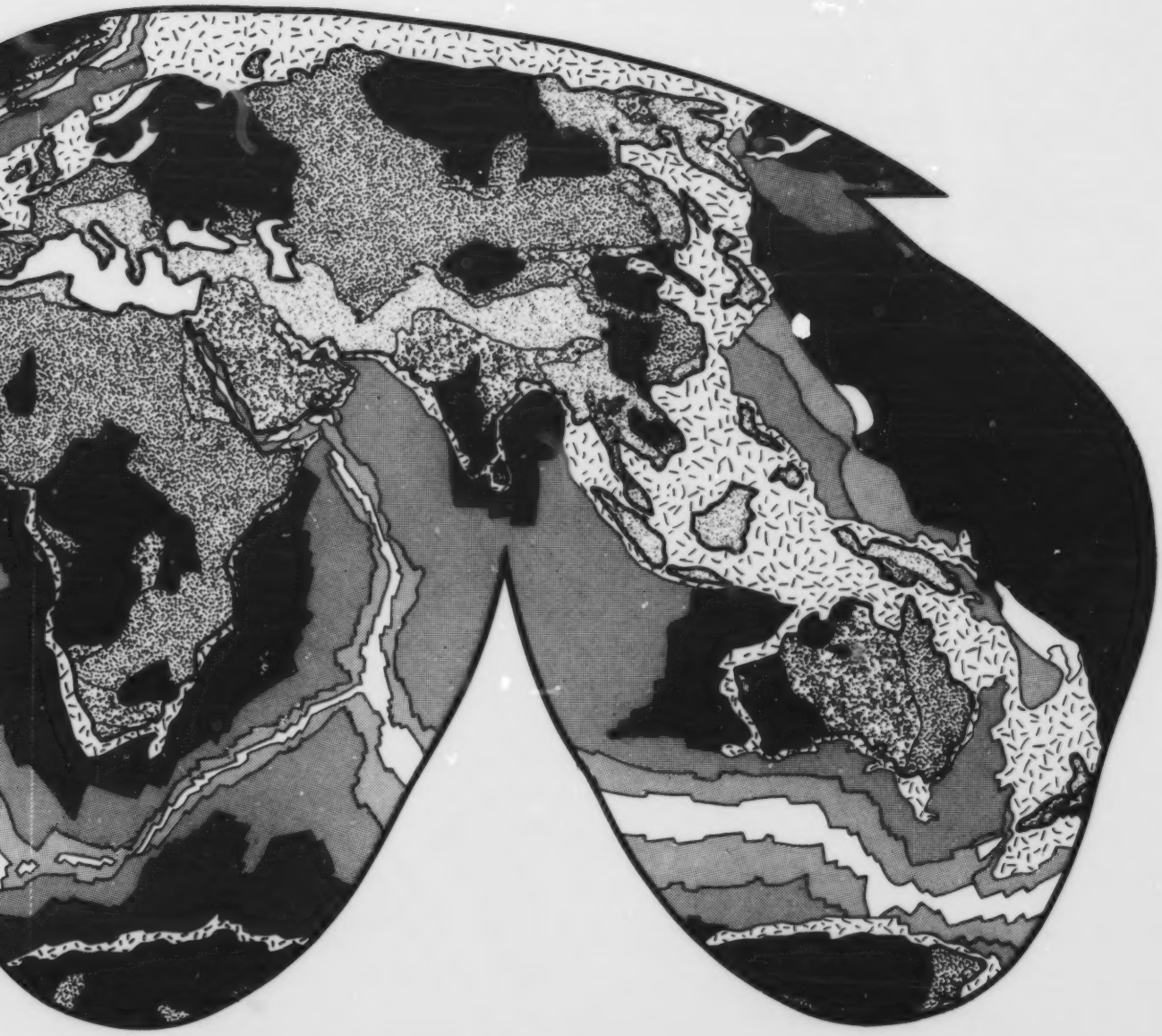
When plates come in contact with each other, the denser, lower-floating plate (the oceanic plate, if it collides with a continental plate) can sink beneath the lighter plate. The edge of the denser plate is pulled downward by gravity, and it slides underneath at a steep angle, sinking into the mantle and ultimately melting.

The pull of gravity at the sinking edge of a plate is the force that powers continental drift. There is very little 'push' at spreading centers, and currents within the mantle appear to have too little strength to make the earth's plates move to the extent that they do. Crustal plates are, in current interpretation, pulled toward subduction zones, and spreading centers represent the thin, weak regions where plates are broken apart from each other, and molten magma can penetrate from the mantle to the surface and form new rock.

New rock that forms at spreading centers consists almost entirely of basalt, the dark, dense material that makes up the bulk of oceanic crust. Nearly all spreading centers are in the oceans (an exception is the Rift Valley of northeast Africa), and oceanic crust receives constant additions at spreading ridges, while it loses material constantly at subduction zones.



Ages of the Earth's crust. The oldest known continental crust is about 19 times as old as the oldest oceanic crust.



Continental Crust

- 0 to 250
- 250 to 800
- 800 to 1,700
- 1,700 to 3,800

Oceanic Crust

- 0 to 9
- 9 to 35
- 35 to 80
- 80 to 140
- 140 to 180

Continental Shelf

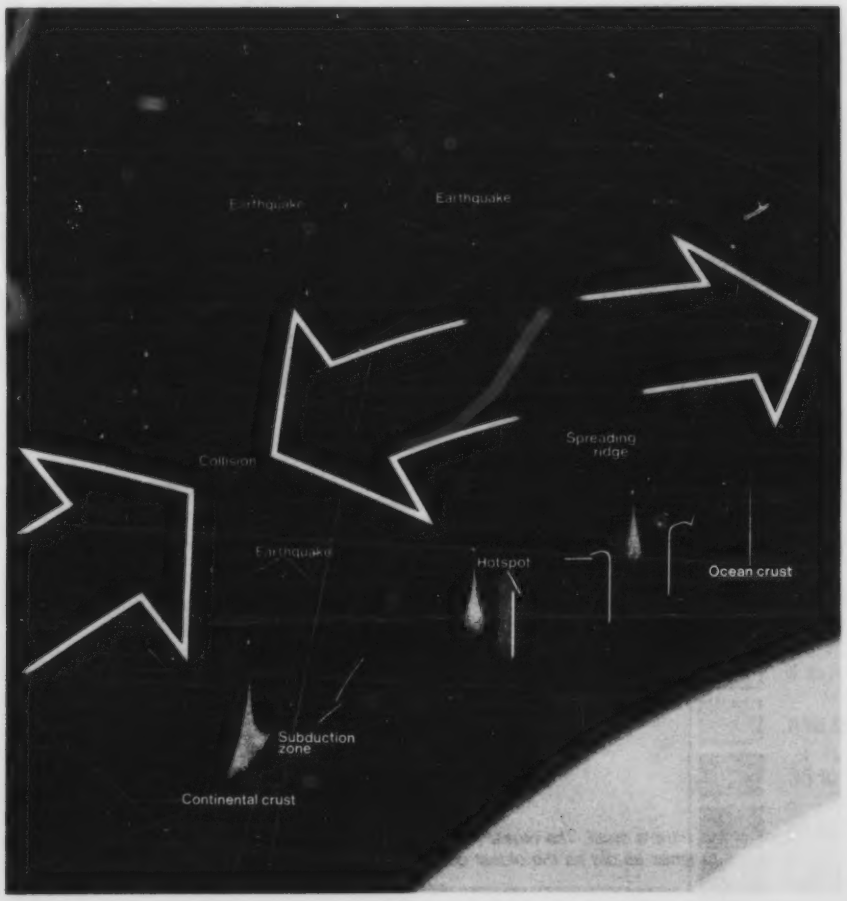
Age in millions of years.

Continental crust is added to by volcanic activity near subduction zones. When dense crust (usually basaltic ocean crust) sinks beneath lighter, higher continental crust the friction between the plates causes continental rocks to crack and bend, and also causes some melting. Molten basalt then rises through major cracks (called **faults**) to the surface, where it causes volcanoes. These volcanic basalts (and gabbros, if the magma does not penetrate to the surface) are denser than the rocks around them, but their effect is not so great as to cause sinking because they are piled up in continental landmasses where huge quantities of lighter rocks, especially granites, predominate. Erosion is the main reason for loss of continental crust, although some continental crust subducts along plate boundaries.

Crustal folding and volcanism usually occur near the edges of continental plates. The earth's mountain ranges are building at continental margins. At present the most active areas surround the Pacific Ocean, where the (oceanic) Pacific Plate is ringed on the north and west with subduction zones, and on the east by spreading centers; and also include southern Asia, where the Himalayas are building as India, a block of continental crust, is subducting beneath lighter, thicker crust of the Eurasian Plate.

Because it is normally the dense oceanic crust that is destroyed during subduction, oceanic crust is 'recycled' much more quickly than continental crust. The oldest known crust in the oceans is less than 200 million years old, but the oldest rocks on the continents are more than 3800 million years old. Thus the ocean's crust has been through at least 19 cycles of creation and destruction while the continents have piled up thicker and thicker, recording nearly all of earth history.

Drifting of the earth's continents, and shifting of its rock layers, affects our area only slowly. Saskatchewan is near the center of the continent, and is in one of the most stable parts of North America. There has been very little shifting here for more than a billion and a half years. Nevertheless, minor earthquakes have occurred in Saskatchewan. Quakes recorded in the Saskatoon and Esterhazy areas (Gendziwill et al., 1982) possibly resulted from shifting of rock in potash mines. At least two earthquakes in the Bengough-Viceroy area, with intensities of less than 4 on the Richter Scale, seem to have been caused by shifting of Precambrian rocks at the boundary between the ancient Churchill and Superior



Dynamic areas of the Earth's crust. New crust is created at spreading ridges and hot spots. Crust sinks downward at subduction zones, and mountains and volcanoes form nearby.

Continents, nearly a kilometre beneath the surface.

In our geological history we have also seen many examples of regional warping, and our area has been raised nearly 900 metres in the past 50 million years, due to subduction of the Farallon Plate under the western edge of North America.

Geological Time

Geological time is one of the most difficult geological concepts to understand. The dates of geological events, and the ages of rocks and fossils, are given in radiometric years, i.e., numbers of years calculated from the rates of decay of radioactive isotopes contained in the rocks or fossils. The numbers themselves are commonly so large (millions or billions of years) that it is pointless to make comparisons with one's own life span, or with the current passage of time.

Perhaps it is best to look at radiometric dates as establishing the order of geological events, their relative duration, and the proportion of the earth's history that separates us from various milestones. For example, the first fossils of hard-shelled invertebrates (trilobites, brachiopods, and the like) occur in rocks about 570 million years old, and thus the record of these and other familiar fossil groups occupies only the last 12 per cent of the earth's history.

Recent research indicates that our species, *Homo sapiens*, may date back 300,000 years, which is a long time but represents only 0.007 per cent of the earth's history. On the other hand, life (at least in the form of primitive bacteria and algae) is known to have existed 3500 million years ago, representing 76 per cent of the earth's history, an impressive record indeed. Although the exact results of these calculations are not very important to know about, they help to appreciate not only the immenseness of time, but also the place of our own area's history in the earth's development.

In the Saskatchewan Museum of Natural History gallery, time is portrayed in two exhibits. One, a geological time line bent back and forth like a snake nearly 21.3 metres long, shows the major divisions of time in correct proportion, with colors and logos that are repeated throughout the gallery whenever a particular period of time is discussed. The other exhibit is a column which gives the name and date of each geological period, and shows where deposits of that age formed in our province. This column also repeats the colors for the periods.

On the large time line we indicate the dates of selected events in earth history, focusing particularly on Saskatchewan events that will be discussed in the gallery. These events occurred in a global context, of course, and it is important to know something about the world's geological history. The following chart lists some other important events and their dates, to put Saskatchewan's geological history into context.

Geological time adds perspective to the earth's story. Although observation of the present is surely the key to the past, and scientists now know a great deal about the earth's past and present processes, it is still vital to observe the sequence of steps that led to the present.

Likewise, Saskatchewan's story, although it does not record all the events that were important in the earth's development, still serves as a good example for the continental interior of North America.

A Geological Cross-section of Saskatchewan

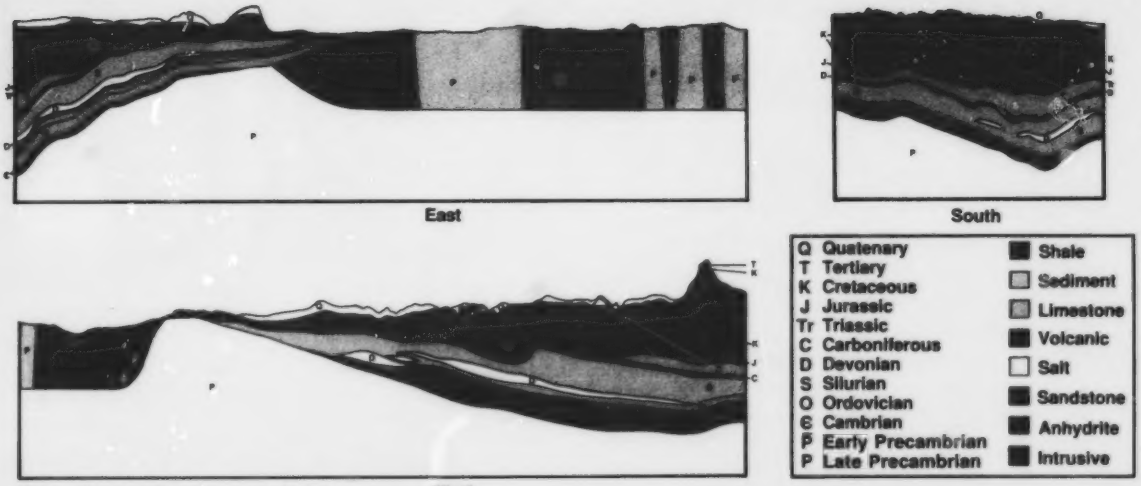
The rock layers that we study and interpret are piled 50 kilometres deep beneath our province. We presume that these rocks represent the entire 4.6 billion years of the earth's history, or at least that part of it during which solid rocks have existed.

Only the rocks that occur at the surface are exposed, however, and areas of **bedrock** exposure where we see the rocks beneath the general covering of soils, recent water-and windborne material, and glacial deposits, are limited. The glaciers of the last two million years were so extensive that they covered nearly all of northern North America, and the last glacier extended south to the Missouri and Ohio rivers in the continent's interior. In Saskatchewan, only the high parts of the Wood Mountain and Cypress Hills Plateaux were unglaciated. Only in these areas, and in places where erosion (river valleys, etc.) has cut deeply into the surface, can we see the older rocks.

Fortunately, tremendous quantities of subsurface data exist because thousands of holes, or 'wells' have been drilled beneath the surface. Not only the rocks and minerals, but in many instances the fossils of these buried rock layers have been sampled.

A three-dimensional model of the upper portion of the crust beneath Saskatchewan shows the known rocks of our province. Our model's horizontal scale is 1:250,000. The sides are cut away at the provincial borders, and all vertical detail is exaggerated 100 times (so vertical scale is 1:2500). Without this vertical exaggeration, the entire Phanerozoic (rocks above the Precambrian) would be only about a centimetre thick, not enough to show detail.

Because the model of Saskatchewan lights up from the inside, the visitor can easily trace the accumulation of rocks from which our story is read. Beneath the other deposits are older Precambrian rocks that contain evidence of the first major events in the gallery, the plate collision, volcanic activity, and mountain-building of two



Types of rocks of various ages found beneath Saskatchewan.

billion to 1700 million years ago. These rocks are colored red on the model.

Then with the erosion of the mountains, a long period of shallow seas followed: the rocks of the younger Precambrian (orange) and Cambrian to Cretaceous (blues and greens) represent these times. The emergence of land in the late Cretaceous (dark green), climatic change and emergence of grassland savanna in the Tertiary (brown), and the advance and retreat of at least five glaciers in the Quaternary (gold) finish the story, and lead to our modern landscapes, life, and environments.

The older Precambrian rocks (colored red) make up most of the crust beneath us. Only a little more than three kilometres depth is shown in our model, so most of the older Precambrian is not depicted. Still, you can easily see how much older Precambrian is present in the Canadian Shield of northern Saskatchewan, and in the 'basement' beneath our younger rocks.

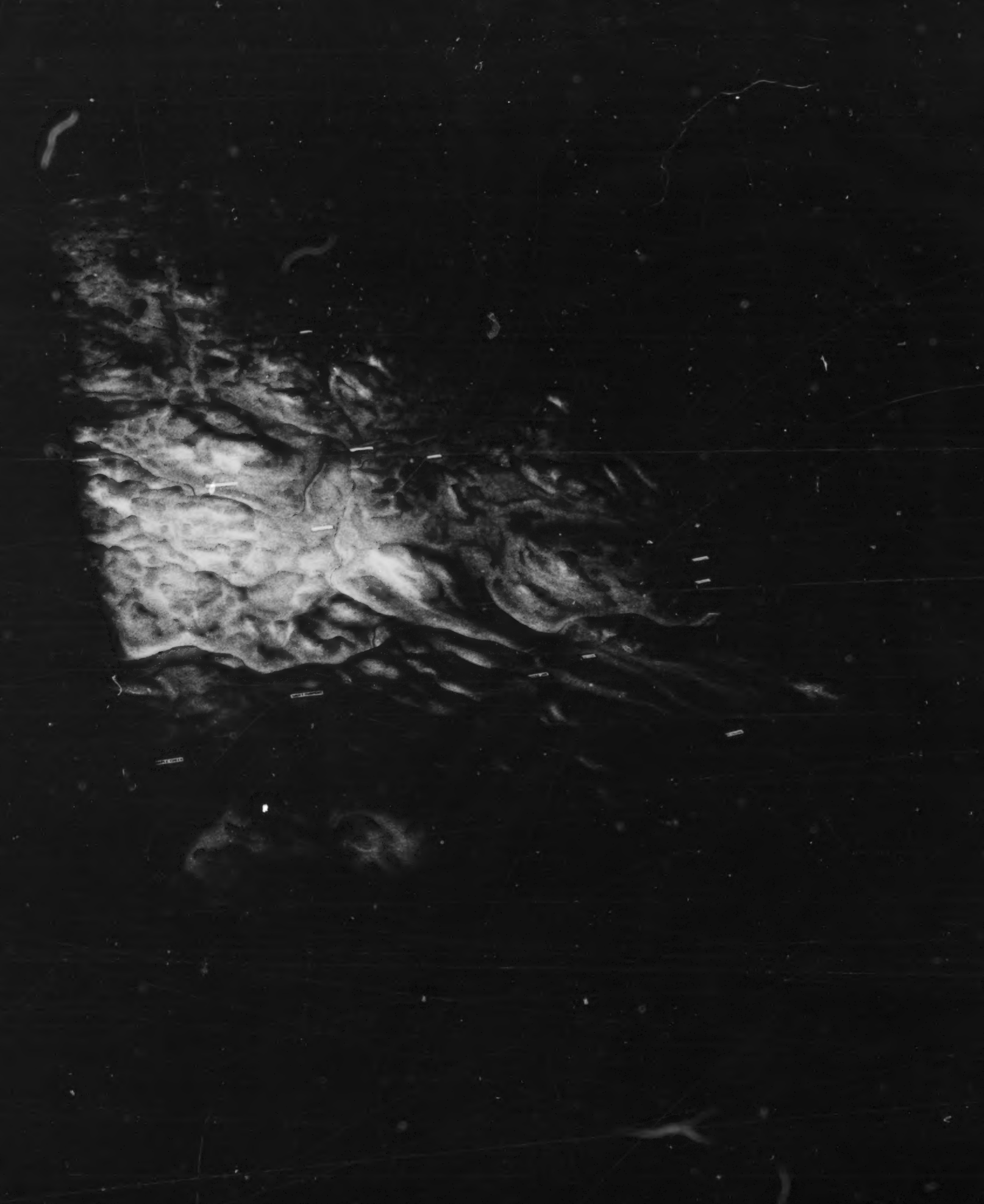
The older Precambrian represents the first three billion years of the earth's history, or nearly two-thirds of the time that has passed since accretion of the earth and moon. Our story starts near the end of this vast period. Only rocks near the surface in the Canadian Shield, and some rocks of the 'basement' have been studied, and most of our earlier history remains to be learned.

The older Precambrian in Saskatchewan is a complex assortment of igneous rocks that were deposited at and beneath the surface, sedimentary rocks formed by their erosion, and metamorphic rocks formed by folding and melting of the igneous and sedimentary deposits. While there certainly were several cycles of tectonism (mountain-building) and deformation, only the last episode emerges with any clarity. Plate separation and opening of an ocean basin was followed by collision, volcanic island arcs, new folding, shearing, and intrusion, and finally full-scale mountain-building. During this time important mineral deposits, including copper, zinc, and gold, were formed in northern Saskatchewan. The axis of the ancient mountains, which was the boundary between the two colliding Precambrian continents, is preserved as a shear zone that extends far to the northeast in the Shield and, after passing nearly beneath Saskatoon and Regina, continues south in the basement to Wyoming.

During and following mountain formation, faulting to the west created basins that filled with sediment eroding from the mountains. The younger Precambrian in Saskatchewan includes only the Athabasca Group, a series of formations in the Athabasca Basin. These sedimentary formations, mostly sandstones, have remained unmetamorphosed since they were deposited a billion and a half years ago. Although no fossils have been found in these rocks, we can surmise that the seas of this time contained cyanobacteria ('blue-green algae') and other single-celled algae and bacteria that had existed through most of older Precambrian time, and some early eukaryotes (organisms whose cells contain nuclei) and multicellular algae that had arisen perhaps 1800 million years ago. The change in the earth's atmosphere from anoxygenic (lacking free oxygen) to oxygenic had occurred only slightly before (1800 m.y.) and complex (metazoan) organisms are not known until near the end of the Precambrian 670 million years ago.

It is in these Athabasca sandstones that most of Saskatchewan's uranium is found. The main high-grade deposits are secondary, and were leached from the original sediments and redeposited near the basin edge.

Our remaining rocks represent the Phanerozoic Eon, which is defined as the time interval during which complex (metazoan) life forms have lived.



Our Saskatchewan rocks represent all the recognized Phanerozoic periods except the Permian, and all our Phanerozoic rocks are sedimentary. No volcanoes or igneous intrusions are known to have occurred here during the Phanerozoic, and earthquakes and faulting/folding of rock layers were never severe enough to cause metamorphism. By and large these rocks were formed in shallow seas that covered the continental interior, though there are many gaps in our geological record. Most of these gaps were probably due to withdrawals of the sea from our area, and non-deposition or erosion during these times. No definite continental deposits (rocks formed in lakes, streams, or flood plains) are known from Saskatchewan until the Cretaceous Period, and our entire Cenozoic record is continental in origin: at about the end of the Age of Dinosaurs, the shallow epicontinental sea withdrew from our province and did not return. Our meager and poorly-understood Triassic deposits may have formed in river valleys, and could be an exception to the above statement.

Our Phanerozoic deposits were almost all laid down in the Western Canada Sedimentary Basin, which is a long, trough-shaped structure southwest of the Precambrian Shield. This basin has been forming since the destruction of the Hudsonian mountain ranges in the late Precambrian, and has steadily deepened throughout much of its history. Nevertheless, certain clues (e.g., the temperatures and pressures that would have been necessary for the formation of oil) indicate that deposits of the Western Canada Sedimentary Basin were once nearly a kilometre deeper than they are today, and that severe erosion, possibly in Tertiary times, has stripped away huge depths of rocks.

The origin of the Western Canada Sedimentary Basin is, to date, unexplained. Perhaps it resulted from regional downwarping due to northeast-southwest pressure at the plate edges. Bedrock highs, originally to the southwest of the basin but later covered by it, include the Swift Current Platform, Alberta Ridge, and Peace River Arch: these may have been the original upwarps.

Although at least three earlier pockets (of Devonian, Jurassic, and Cretaceous rocks) occur in the Shield area, the only widespread Phanerozoic deposits of northern Saskatchewan are Quaternary in age. Pleistocene glacial deposits cover the entire province except for some of the southern plateaux, and particularly spectacular features including drumlin fields and long eskers can be found in the north. These glacial deposits, and the recent (Holocene) soils, dunes, and stream beds that cover them, mark the end of our geological history so far.

Although the Western Canada Sedimentary Basin is by far the largest sedimentary basin in the Canadian Great Plains, one of its parts has its own story. The Williston Basin, whose center is in North Dakota, extends well into southeastern Saskatchewan. It appears on the block model as the deepest area of Phanerozoic deposits in Saskatchewan, nearly three kilometres deep. The Williston Basin began sinking independently of the rest of the Western Canada Sedimentary Basin in Ordovician time, about 450 million years ago. This sinking took place at a much greater rate than in the rest of the basin, but still slowly enough that the carbonate banks and inter-bank detrital deposits of the Ordovician-Silurian grew quickly enough to fill the Williston Basin. Likewise, the great coral reefs and evaporite deposits of the Devonian grew more quickly in the Williston Basin than they did in the surrounding areas. Consequently, when we look at Saskatchewan's buried deposits in cross-section, the Williston Basin appears as a markedly thickened area of Ordovician to Paleocene (earliest Tertiary) rocks. For nearly 400 million years this smaller part of the Western Canada Sedimentary Basin was the most important crustal feature in the western Canadian Plains.

There is at present a significant controversy over the beginning of the Phanerozoic Eon, and thus the beginning of the Palaeozoic Era. Cloud (1968) proposed a new geological period, the Ediacaran, to include rocks about 670 to 590 million years old that preserve the first known faunas of complex organisms, but preceded the earliest 'shelly' faunas of molluscs, tube worms, reef-building archaeocyathids, and other organisms with hard shells. These Ediacaran rocks (many geologists use the Soviet term Vendian) usually lie above late Proterozoic glacial deposits, and are found in Australia, Namibia, southern China, Siberia, Russia, Scandinavia, England, Newfoundland, eastern British Columbia, and eastern California. The fossils include jellyfish-like animals, segmented worms, and soft-bodied arthropods, and represent organisms that lived on the continental shelf, around a supercontinent that straddled the equator in the late Precambrian.

Cloud and others argue that the beginning of the Phanerozoic Eon, previously defined by the appearance of abundant advanced life forms in the Cambrian, should be moved downward to include the Ediacaran faunas, and that the lower boundary of the Palaeozoic Era should similarly be moved downward by inserting a new, earliest Palaeozoic period (Ediacaran). Others continue to recognize the appearance of hard-shelled organisms as the most important event, and the concept of the Precambrian-Cambrian boundary is so firmly entrenched in the scientific literature that a downward extension of the Palaeozoic is unlikely in the near future.

CHAPTER 2

The Precambrian

The Precambrian is a term generally used to include the earth's entire history prior to the Cambrian Period, in which the first organisms with hard shells appeared. As we have seen, these were not the earliest complex (metazoan) organisms, which had appeared nearly 80 million years before the Cambrian, in Ediacaran (Vendian) sediments.

'Precambrian' is not a recognized term for an eon, era, or period, although it is widely cited and is firmly entrenched in the literature. Many texts recognize three eons, or spans of time equivalent to the Phanerozoic Eon in which we live. These are the Priscoan, the time between the accretion of the earth and the solidification of the first crustal rocks (4.6 billion to 4 billion years ago); the Archean, stretching up to 2.5 billion years ago when the Kenoran Orogeny created a great mountain range in northern Ontario; and the Proterozoic, lasting until 590 million years ago and including the development of organisms with nucleated cells and, finally, the first complex organisms.

We have divided the Precambrian somewhat differently, to provide a scheme that fits Saskatchewan's geological history more closely. Our 'older Precambrian' ends near the height of mountain-building activity about 1800 million years ago, and the 'younger Precambrian' includes the erosion of the mountains, the beginning of our best-known shallow equatorial seas, and the deposition of uranium. Thus the 'older Precambrian' is the time of dynamic activity (plate movements), volcanoes, and mountain-building, and emplacement of metallic ores in northern Saskatchewan. Although the evidence is not yet clear in our province, our dividing line of 1800 million years marks an important series of events in the earth's history, the change from an anoxygenic to an oxygenic atmosphere and origin of organisms with eukaryotic (nucleated) cells.

Although the story in our gallery begins with Precambrian volcanoes and mountains nearly two billion years ago, we can be certain that a great deal went on here before then. We know of continental crust that is much older, and the oldest radiometrically dated rocks in northern Saskatchewan are 3100 million years old, a date roughly contemporaneous with the occurrence of bacteria and blue-green algae in rocks of the Transvaal, South Africa.

Evolution of the Trans-Hudson Orogen (Mountain Belt), 2.1 to 1.8 Billion Years Ago

Dr. J.F. Lewry, Department of Geology, University of Regina

From about 2.5 to 2.1 billion years ago, Saskatchewan and Manitoba formed part of a large ancient continent. This continent was composed of rocks ranging in age from about 2.5 billion to more than 3.1 billion years old. Such rocks formed during the **Archean** Era of Earth's history. The continent covered most of what is now the Northwest Territories and Canadian Arctic and extended into Wyoming and Colorado. It is unclear whether central-eastern Canada was part of this landmass or was part of a separate Archean continent.

About 2.1 billion years ago, in the middle of the early **Proterozoic** Era, this continent (or continents) underwent rifting and breakup, with ensuing continental drift and development of a major ocean between the continental fragments. The geography of Saskatchewan during early stages of this rifting may have been analogous to the present-day Red Sea-Gulf of Aden scenario, which marks rifting of the African and Arabian plates and beginning of development of a new intervening ocean.

Ensuing events, eventually culminating in development of a major mountain belt, or **orogenic belt**, comparable to the present Alpine-Himalayan chain, are portrayed in a simplified way in the following diagrams, which cover northern Saskatchewan and Manitoba. These reconstructions involve some speculative interpretation but are based on the latest available geological information.

1. *2100 to 2000 Million Years Ago: the 'Passive Continental Margin' Stage.*

About two billion years ago, the area now forming the Saskatchewan-Manitoba Shield may have looked rather like the present-day Atlantic Ocean and adjacent continental margin of North America. Rivers carried sediment into the ocean from a **Churchill** landmass that lay somewhere to the northwest; perhaps covering part of Saskatchewan or lying farther west in the Northwest Territories. Sediments were deposited on a broad, shallow continental shelf.

The true margin of the continent was marked by an underwater scarp, the **continental slope**, that descended to the **abyssal plain** some 3000-6000 metres below sea level. As in modern oceans, crustal rocks underlying the abyssal plain were quite different from the granitic rocks that form the continents. They consisted of dense basalt lavas erupted along a mid-oceanic rift valley. On either side of the rift, a submarine mountain chain stretched along the length of the ocean (as in the present-day North Atlantic Ridge), perhaps rising above sea level in places to form volcanic islands like those we see today in Iceland or Tristan da Cunha. Each eruption of lava contributed to the creation of new oceanic crust. Earlier-formed lavas were gradually displaced and moved farther and farther from the central rift. Thus the ocean floor slowly widened as new material was constantly added at the centre; towards the margins of the ocean, the crust became progressively older. This process is called **seafloor spreading**.

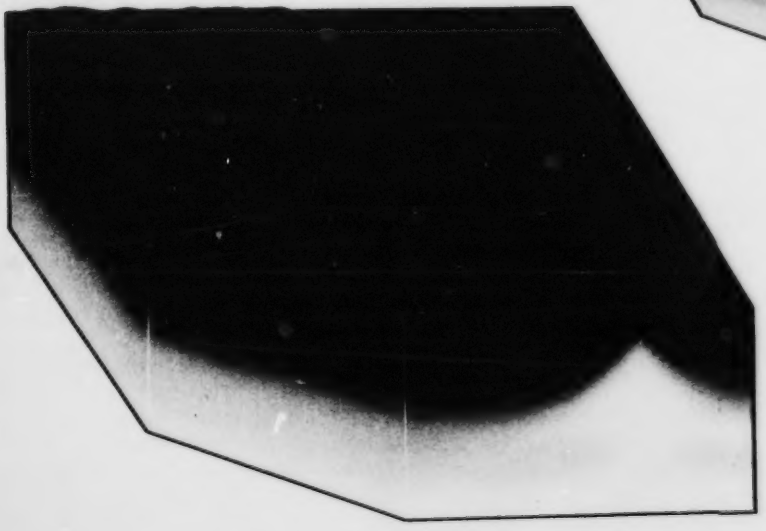
The seafloor spreading process also generates **transform faults** that split the oceanic ridge into numerous offset segments. As long as new ocean floor was created, the ocean covering much of Saskatchewan and Manitoba continued to widen, but this could not go on indefinitely. By about 1900 million years ago, a new phase of crustal evolution was in progress.

2. *1900 to 1875 Million Years Ago: Early Island Arc Development.*

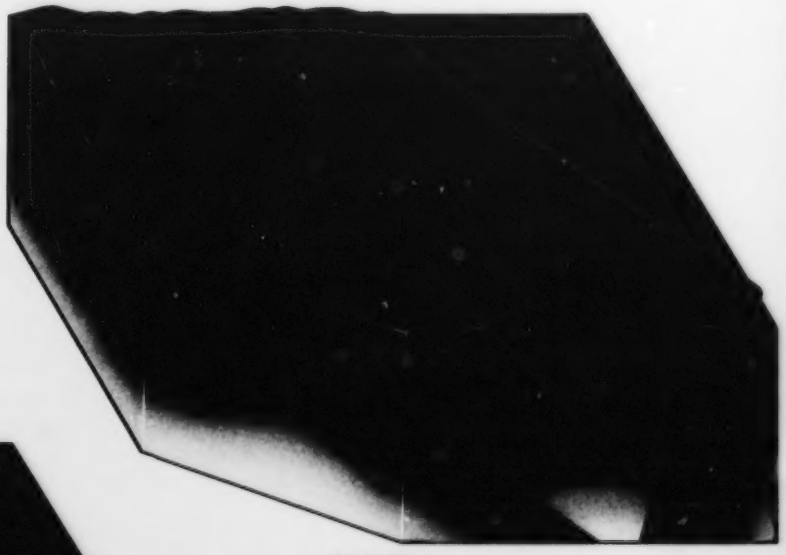
The tectonic plates that form the earth's rigid **lithosphere** (including the crust and upper mantle) are in constant relative motion, in places splitting apart, elsewhere moving towards each other or sliding past each other. About 1900 million years ago, the situation in Saskatchewan and Manitoba changed from Atlantic-type passive margin development to one of plate convergence comparable to the modern situation in the western Pacific. The denser oceanic lithosphere was fractured and in places began to sink downwards beneath the edges of adjacent advancing tectonic plates. The inclined zones of underthrusting created by this movement are called **subduction zones** and are marked at the surface by deep ocean trenches. The deepest such trench known at the present-day, the Marianas Trench, extends more than 11,000 metres below sea level. The oceanic crust dragged down along these subduction zones is carried into the hotter underlying mantle, the **asthenosphere**. Most of the sediments that covered its surface are scraped off and deformed in the **subduction complex** as the plates descend, but the subsiding plates are subjected to increasing pressures and temperatures and at a depth of 100 to 300 kilometres below the surface will start to melt. Such subducting plates can descend to depths of about 700 kilometres.

Mountain Building

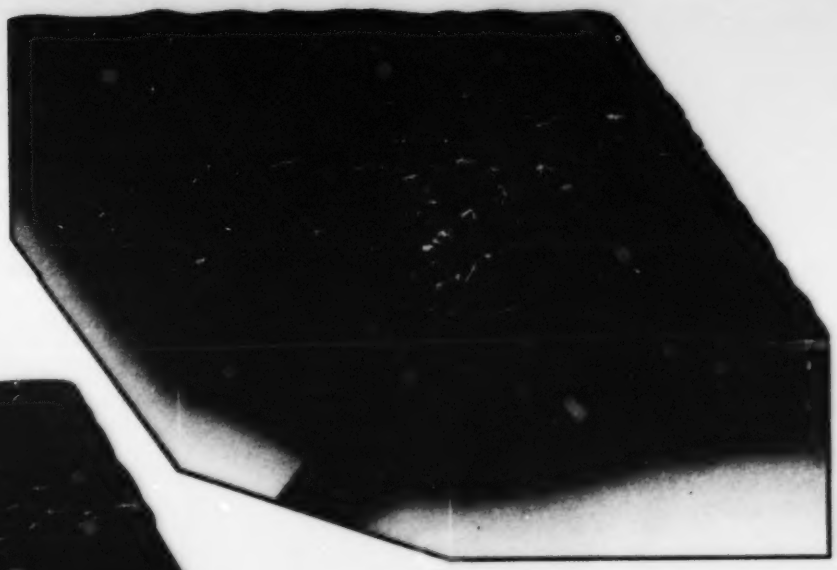
- Unreworked or mildly reworked Archean basement
- Continental crust – highly reworked Archean basement
- Oceanic Crust
- Upper Mantle
- Mafic and Ultramafic intrusions
- Early Proterozoic volcanic rocks (basalt and rhyolite)
- Early Proterozoic intrusions (granite, granodiorite, quartz, monzonite)
- Early Proterozoic intrusions (quartz, diorite, tonalite, tronojemite, granodiorite)
- Early Proterozoic shelf sea and foreland basin sediments
- *Subducted island arc sediments*
- Athabasca sandstone
- Cambrian and later rocks
- Early Proterozoic sediments derived from erosion of island arcs



PHASE I
The spreading ocean 2100 to 2000 million years ago; the passive continental margin.

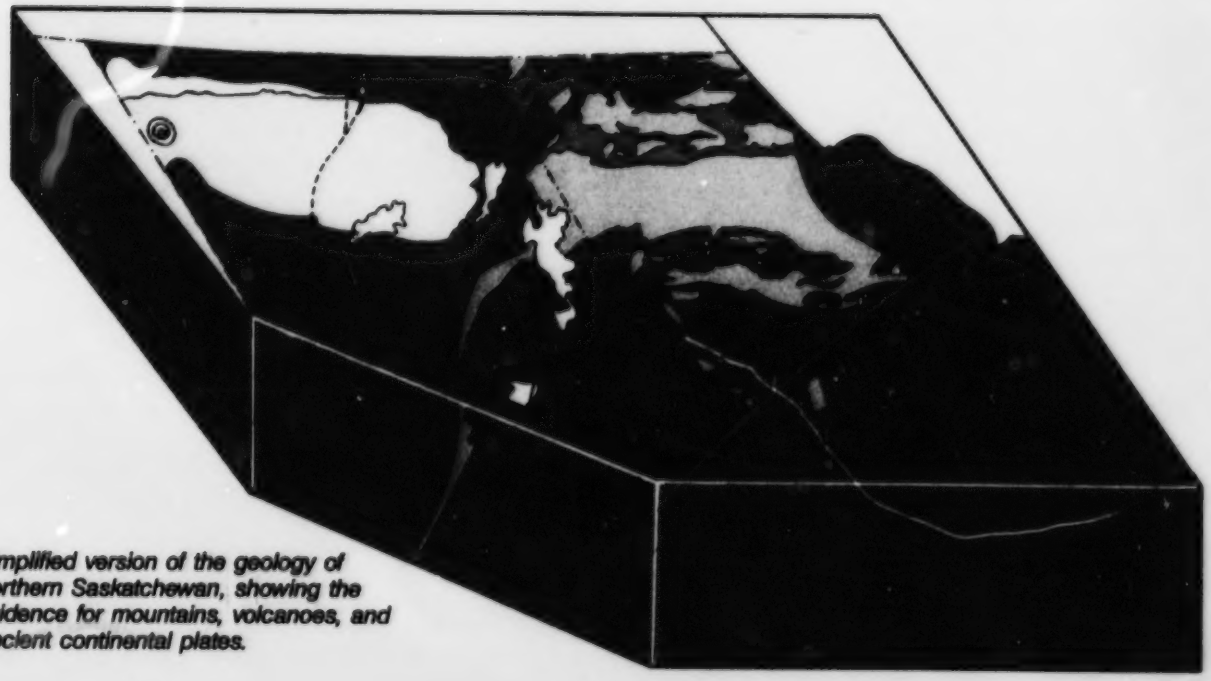


PHASE II
Early island arcs 1900 to 1875 million years ago.



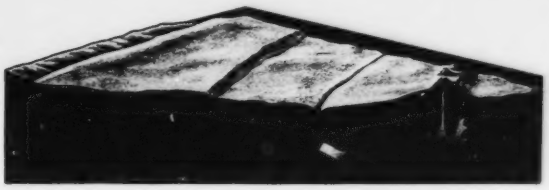
PHASE III
The arc collision stage 1860 to 1850 million years ago; ocean basin is destroyed and mountain-building begins.

PHASE IV
The climax of mountain-building, 1830 to 1800 million years ago: Himalayan style continental collision.



Simplified version of the geology of northern Saskatchewan, showing the evidence for mountains, volcanoes, and ancient continental plates.

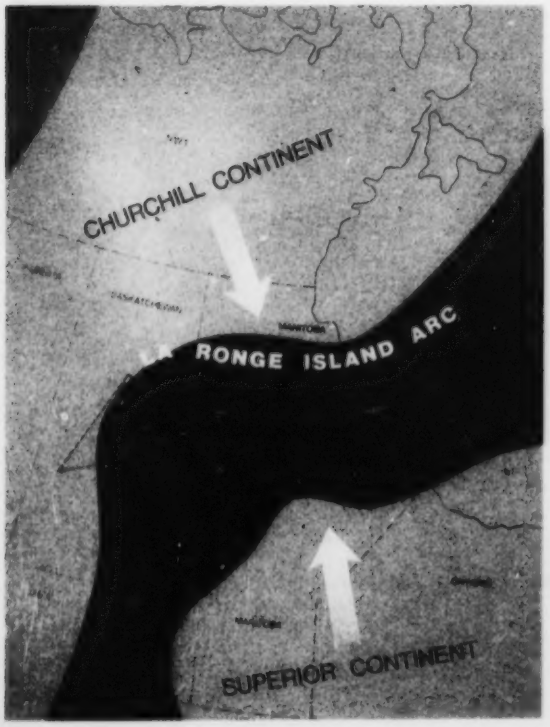
below the surface before movement is impeded and the plate is re-absorbed back into the mantle.



Formation of the LaRonge island arc. A chain of volcanic islands formed as oceanic crust sank beneath another plate, then melted partially. Magma rose through cracks and faults to erupt at the surface.

Hot fluid **magma** derived from melting of the downgoing plates and overlying mantle rises towards the surface. Some is emplaced as igneous intrusions but much is erupted at the surface to form a chain of volcanic islands. Together with scraped-off sediments in the subduction zone and sediments derived from erosion of the volcanoes, chains of islands known as **island arcs** are formed above the subducting plates. Many such arcs exist on earth today, for example in the Aleutians, the Kurils, Japan, the Marianas, and Indonesia. The Early Proterozoic island arcs of Saskatchewan probably developed in a setting something like that seen in the area between the Philippines and the Mariana Islands at the present time. This early stage of arc development in Saskatchewan may have terminated about 1870 to 1860 million years ago.

3. *1860 to 1850 Million Years Ago: The Arc Collision Stage.*



By about 1850 million years ago convergence of the two tectonic plates had reached a more advanced stage. Most of the previously formed oceanic lithosphere had probably been subducted back into the mantle and another continental mass was moving in from the southeast. The island arc to the northwest (eventually to become the present-day La Ronge-Lynn Lake Volcanic Belt) had collided with the continental margin to the northwest after intervening oceanic crust had been completely consumed in the subduction zone. As collision took place, the volcanic rocks and sediments of the island arc, and the sediments that once covered the adjacent continental shelf were compressed, deformed and uplifted to form a new mountain belt along the new continental margin. When this occurred, a new subduction zone dipping in the opposite direction probably developed to the southeast. Molten granitic material from this newly subducted plate crust and from the overlying heated continental margin was emplaced to form the huge **Wathaman Batholith**, stretching some 800 kilometres across what is now Saskatchewan and Manitoba. Other molten material erupted onto the surface from volcanoes. The present-day Cordillera (Rocky Mountains and coast ranges), stretching through Alaska, British Columbia and the western United States, developed in part from a series of similar continental margin-arc collisions over the past 150 million years and includes huge intrusions like the Wathaman Batholith.

With no land vegetation to cover and protect the exposed rocks at this stage in earth history, weathering and erosion would have been rapid. As the mountains were lifted they were rapidly stripped and huge quantities of sediment were deposited at their margins and in the adjacent ocean. These sediments would be involved in the next stage of mountain building.

Offshore, a chain of volcanic islands marks the location of the second of the island arcs (eventually to become the present Flin Flon-Snow Lake Volcanic Belt). By this time the oceanic crust which once lay to the east may have already been completely subducted beneath the arc. The margin of the incoming continental landmass that now forms the Superior Province had been carried eastwards during gradual closing of the intervening ocean basin and was itself now starting to be subducted. This marks the

beginning of terminal continent-arc-continent collision. The stage portrayed here is analogous to that which exists today between Australia and the islands of Sumatra and Java. The Indo-Australian Tectonic Plate is currently moving northward, colliding with the huge Eurasian Plate. The Indonesian island arcs represent one segment of this collisional boundary. A slightly more advanced stage in the process is represented by the present relationship between the Alps, Mediterranean Sea and North African continental margin.

4. 1830 to 1800 Million Years Ago: Continental Collision.

In northern India, this collisional process has proceeded still further. Continued convergence has resulted in collisional welding of the Indian and Central Asian continental plates and creation of the Himalayan mountains: the wide ocean that formerly lay between these landmasses has completely disappeared. Similar events occurred in Saskatchewan between about 1830 and 1800 million years ago when the Superior Continent collided with the Churchill Continent. The thick, relatively less dense Superior continental crust could not subduct as easily as the oceanic crust had done but was driven in underneath the arc volcanics and sediments during the collision.

Massive compression, folding, fracturing and heating of all rocks involved would have taken place.

Huge folded slices (**nappes**) of oceanic sediments and volcanic rocks were thrust over each other, and over the incoming Superior Continent, to produce massive crustal thickening in the core of the developing mountain belt. Because this thickened continental crust was less dense than the underlying mantle it was lifted to produce a great range of mountains, part of which ran through Saskatchewan and Manitoba.

Continued uplift was accompanied by constant weathering and erosion which stripped off the surface rocks and eventually exposed the igneous intrusions and highly deformed rocks that were once buried deep within the crust. The granites and metamorphic rocks we see today in northern Saskatchewan represent the deeply eroded roots of the ancient mountain chain and the still older adjoining Archean continent.

5. The Present Situation.

This diagram shows a simplified version of the present-day situation. The Trans-Hudson mountain-building event was completed by about 1760 million years ago, aside from minor crustal movements along pre-existing faults. Over the next 100 million years or so, the huge mountain belt was thoroughly eroded to become a low relief area of a new major continental mass formed by the preceding collisional events. Part of the new continent eventually became the North American Precambrian Shield, the main exposed part of which is the Canadian Shield. About 1600 million years ago, westward-flowing river systems deposited the Athabasca Sandstone along the western part of the now completely eroded mountain system. These sandstones were laid down under continental to shallow marine conditions and are now partly preserved in the Athabasca Basin in northern Saskatchewan.

Since then, Saskatchewan and Manitoba have been part of a stable continental area, little affected by younger mountain-building episodes which formed the Appalachians and Canadian Cordillera. Since 590 million years ago, a relatively thin succession of Phanerozoic sediments, mostly deposited in intermittent shallow seas, has been laid down across the region. These sediments now cover the old eroded Trans-Hudson mountain belt in the southern two-thirds of Saskatchewan.

The Amisk Volcano

The shield volcanoes that arose as the continents drifted together and oceanic crust was subducted were relatively low and broad like the famous Mount Fuji or Mount Kilimanjaro. They not only covered huge areas with basaltic lavas (appearing as pillow lavas) but also laid down the sulphide deposits that are major sources of copper and zinc in the Flin Flon area. Subsequent faulting and metamorphism, and the production of associated molybdenite deposits, followed at least three times.

Shield volcano of the kind that formed in Saskatchewan nearly 1900 million years ago. (display photo)

Although hydrothermal vents were discovered near the East Pacific Rise only in 1977, scientists had hypothesized their existence for some time. The

Black smokers, the chimney-like vents through which mineral sulphides reach the ocean floor.

actual discovery was even more surprising than the theory behind it. 'Black smokers,' tall chimney-like projections from the sea floor, pour out streams of sulphide minerals dissolved in water at 350°C. It appears that these minerals are formed by ocean water which seeps through cracks in the sea floor and reacts with molten magma beneath the surface. The resulting sulphides of iron, zinc, and copper erupt through the sea floor, building the chimneys of the 'black smokers' as they go, and eventually coating the ocean floor with a layer of minerals. In the modern oceans, the hydrothermal vents allow unique animal communities to live around them, but in Precambrian times only a limited assemblage of

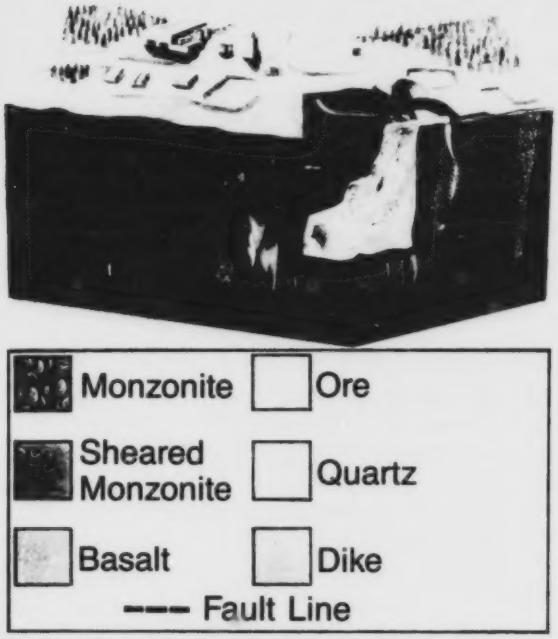
Pillow lavas, formed as molten lava cools in water.

organisms were alive to take advantage of the warm, nutrient-rich waters.

In our gallery model, you can see how molten material can erupt through the top of the volcano (a caldera eruption) or the side of the volcano (a fissure eruption), and how mineral ores erupt through black smokers. The model is based on an actual Precambrian volcano near Amisk Lake. Geologists know where the original volcano was and how it operated, from the distribution of erupted lava, intrusive (unerupted) rock, and mineral deposits. The prevalence of pillow lavas indicates that most of the volcano was beneath the surface of the water, because cooling of hot lava in water to produce a thin skin of volcanic glass is what creates the distinctive pillow shapes.

Gold Deposits: The Star Lake Orebody

The folding and faulting of the Hudsonian Orogeny caused considerable breakage and shearing of the older rocks. This shearing, and the accompanying intrusion and metamorphism, was responsible for emplacement of additional mineral deposits that have major economic importance.



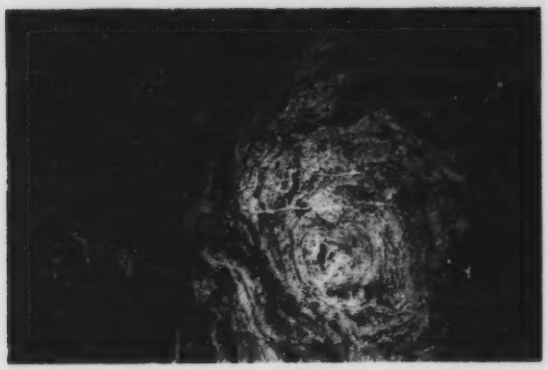
Star Lake gold mine. The orebody, mining camp, and mine workings are shown.

To illustrate these deposits we have constructed a model of the Star Lake gold mine with the kind cooperation of Cameco (formerly the Saskatchewan Mining Development Corporation).

The orebody at Star Lake is like many in the north. The original rock in the area was a relatively uniform monzonite, an igneous rock made up of feldspar, mica, and hornblende, formed at least 1880 million years ago.

Shearing from the pressures generated by mountain-building caused some alteration of the monzonite, deforming and aligning the feldspar

crystals. This shearing created weak zones into which basaltic dikes intruded. Molten quartz also intruded into the areas weakened by shearing and, when the quartz hardened, ore minerals crystallized within the quartz veins. The gold at Star Lake is not seen as visible gold, but occurs



Stromatolites, layered structures built by blue-green algae, or cyanobacteria. (Robert J. Long photo)

with pyrite, commonly called 'fool's gold.' Pyrite does not usually contain gold, except in special circumstances like Star Lake.

To extract the gold from orebodies like Star Lake, it is necessary to break up the pyrite-containing quartz veins, crush the ore in a huge mill, then separate the gold from other rocks and minerals by chemical means. Although it takes nearly a tonne of ore to produce one ounce of pure gold, the process is profitable enough that several gold mines are opening in northern Saskatchewan, and active exploration continues.

The Ancient Mountains Eroded Away

After the climax of the Hudsonian Orogeny, block faulting to the west of the major mountain range produced rift valleys and basins that filled with sediments eroded from the mountains. The major surviving evidence is in the deposits of the Athabasca Basin. An early rift valley in the Uranium City area (dated at nearly 1800 million years before the present) contains unmetamorphosed, uranium-bearing redbeds of the Martin Formation: in these deposits are found Saskatchewan's earliest known fossils, stromatolites, which are mounds of calcareous sediment built by cyanobacteria, or 'blue-green algae.' Stromatolites are still created today in intertidal flats in western Australia and some atolls of the Indian Ocean and South Pacific.

More than 1600 million years ago, subsidence of the western part of the Athabasca Basin started, with deposition of clastics derived from the Hudsonian mountains to the east. Throughout its history, the Athabasca Basin has acted as a series of major fault blocks rather than as a unified downwarp basin.

The first areas of deposition were the Jackfish Sub-Basin and Mirror Sub-Basin, and the earliest identified deposits were marine, though major portions of the basin system contain deposits from rivers and lakes. Ramaekers (1980) has reconstructed a complex history for the basin involving at least 515 million years and four marine transgressions that affected all but the eastern third of the Athabasca Basin. A major emplacement of basic intrusives in the central part of the basin occurred from about 1360-1000 million years before the present. All in all, as much as 5500 metres of deposits may have filled the Athabasca Basin, of which 1000-2000 metres remain. The rest has been removed by erosion.

Most important uranium deposits associated with the Athabasca Basin are sedimentary in origin. Some of the orebodies have their roots in the basement, but most are concentrated in the sandstone near the sandstone-basement

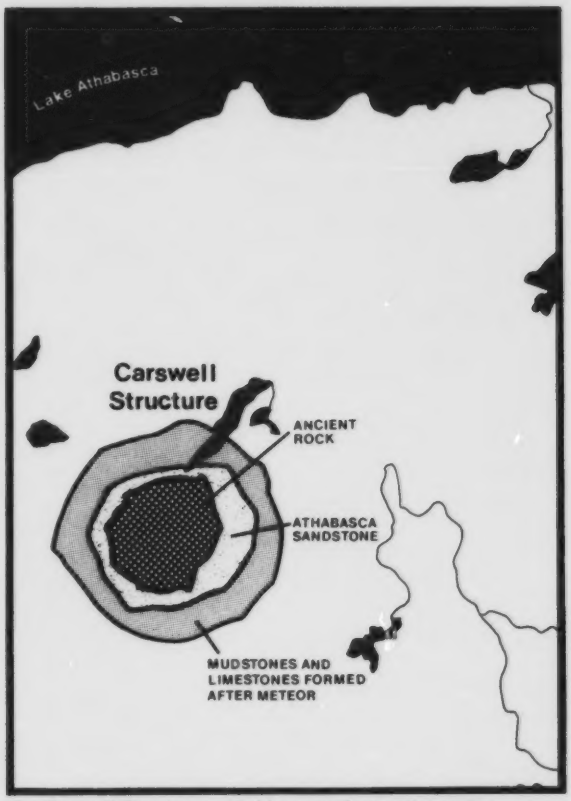
Erosion and deposition. The ancient mountains wore away, creating new deposits in downfaulted basins. (display photo)

unconformity. Ramaekers (1980) considered that most uranium was originally present in tuffs of the marine shelf Wolverine Point Formation: Wolverine Point deposition occurred about 1600 million years ago. A major episode of intrusion, faulting, and deep burial of earlier sediments occurred from 1300-1000 million years before the present. Changes in the tuffs with deep burial released uranium to formation waters, which precipitated the mineral at chemical traps near the basin edge. In some areas we now find concentrated uranium deposits, including the deeply buried orebody at Cigar Lake. That ore is so highly radioactive in its raw state that people cannot safely approach it. Mining will have to be done entirely mechanically, and controlled from a distance.

The last billion years in the Precambrian Shield have seen almost entirely erosional events, with the exception of minor Devonian and Cretaceous marine transgression and deposition. Although the Athabasca Group contains the youngest Precambrian deposits known in Saskatchewan, no latest Precambrian or earliest Phanerozoic rocks are present to record the emergence of complex life forms in the shallow seas of Saskatchewan. No fossils are presently known from the Athabasca Group.

A later event of considerable interest was the development of the Carswell Structure, in which Cluff Lake and its economically important deposits are situated. Most geologists think that after a long period of erosion in the late Precambrian and early Palaeozoic, a meteorite impact, possibly of Ordovician age, removed the upper rock layers and caused faulting around the crater's edge. Subsequent rebound refilled the crater from below, bringing rocks of the deep basin to the surface. Among the rocks exposed in this manner were sandstones that contained abundant uranium, from the very bottom of the basin giving rise to the rich Cluff Lake deposits.

An alternative explanation of the Carswell Structure by Currie (1969) compared the structure



The Carswell Structure, probably an ancient meteor crater.

to modern pingoes in the Arctic, and considered that buoyant forces within the basin were responsible.

CHAPTER 3

Palaeozoic Era

Throughout the Palaeozoic Era, our story depicts Saskatchewan as being covered by a shallow, tropical sea (until the later Palaeozoic, an equatorial sea). These seas are called **epicontinental**, because they sat on the continental craton rather than in ocean basins.

The concept of shallow seas covering the area for hundreds of millions of years, while it represents a fundamental stage in our geological history, is not perfectly correct. Major deposits of marine origin alternate with gaps in the geological record, probably representing times when oceans retreated temporarily, land was emergent, and erosion predominated. It is usually difficult to be sure that land was actually emergent during these times, because continental deposits for the intervals in question have not been discovered. Massive erosion is more likely on land than in the ocean, however.

These Palaeozoic rocks are the source of our economic deposits of helium and potash, and some Palaeozoic rocks, especially Devonian and Carboniferous, contain oil and gas. The only known source rock for oil in our area, the early Carboniferous Bakken oil shale, is also of Palaeozoic age.

Though Palaeozoic rocks are not extensively exposed today, and their history is one of gradual deposition in epicontinental seas, this era was extremely important in our geological evolution and in the accumulation of Saskatchewan's mineral resources. The Palaeozoic rocks of the world trace major advances in life, beginning with the first appearance of communities of hard-shelled animals, and continuing to include the first vertebrates, fish, land plants, insects, amphibians, and reptiles. Major advances among plants included the appearance of the first gymnosperms, plants bearing naked seeds.

Cambrian Period

Deep in the Western Canada Sedimentary Basin are sandstones and shales of Cambrian age (590 to 505 million years ago). These rocks extend to the Rocky Mountains, where their equivalents are exposed by folding and faulting, and underly most of the southern half of Saskatchewan. They are not exposed in Saskatchewan, and are known only from deep drill holes. No Cambrian fossils are known from our province. The earliest of our Cambrian deposits are about equivalent in age to the Burgess Shale of Kicking Horse Pass, near Field, British Columbia, which has produced a famous fauna of trilobites, other arthropods, and soft-bodied animals.

By studying the distribution of Cambrian rocks, and their relative coarseness in various parts of the plains, geologists have concluded that our Cambrian sediments were eroded from the Canadian Shield to the east. The spine of our ancient mountains had eroded away to the extent that it was no longer a major contributor of sediments by 550 million years ago. On the west, there was no nearby feature high enough to erode sediments into our Cambrian sea, and mountain-building activity in the Rocky Mountains did not begin until the Devonian. Our Cambrian sea sat to the west, advancing eastward from time to time across areas of Shield. Accordingly, western Alberta has a greater range of Cambrian deposits than does Saskatchewan.

Cambrian deposits near Swift Current have been found to contain major quantities of helium, possibly originating in Precambrian rocks and trapped in the Cambrian sandstones. For many years helium was extracted at a plant north of Swift Current.

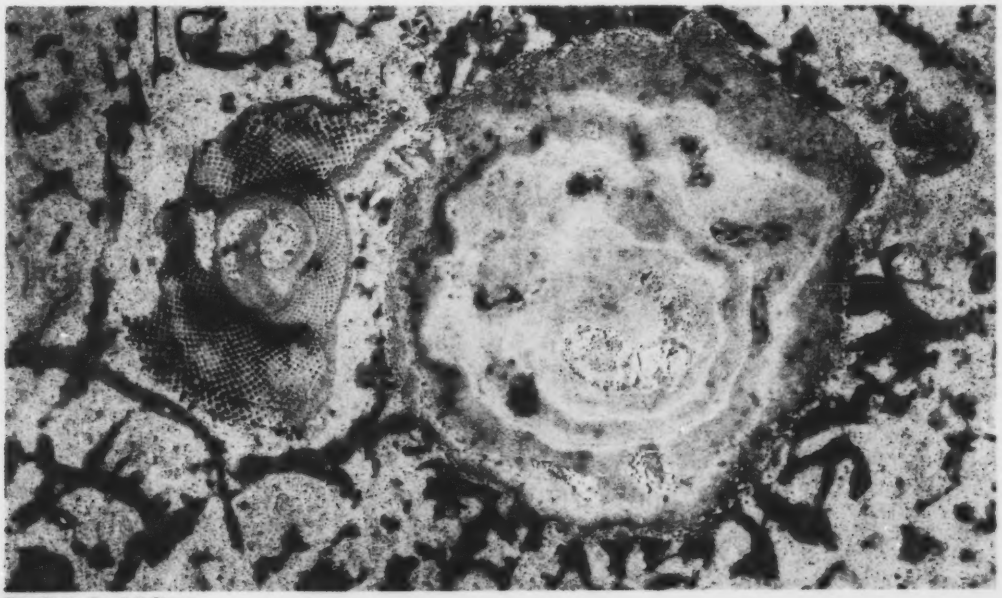
A minor amount of oil has been extracted from Cambrian deposits of the Williston Basin in North Dakota. By and large, drilling has not penetrated as deeply in equivalent rocks of southeastern Saskatchewan, and at present petroleum is not an important aspect of our Cambrian deposits.

Ordovician Period

Ordovician rocks are very familiar to people in our area, because they are commonly used as building stones such as the Tyndall stone that faces the Saskatchewan Museum of Natural History, the Legislative Building, and many other buildings. Although Tyndall stone is quarried near Winnipeg and shipped from there to other parts of Canada, identical rock is found as glacially-transported fieldstones throughout southern Saskatchewan.

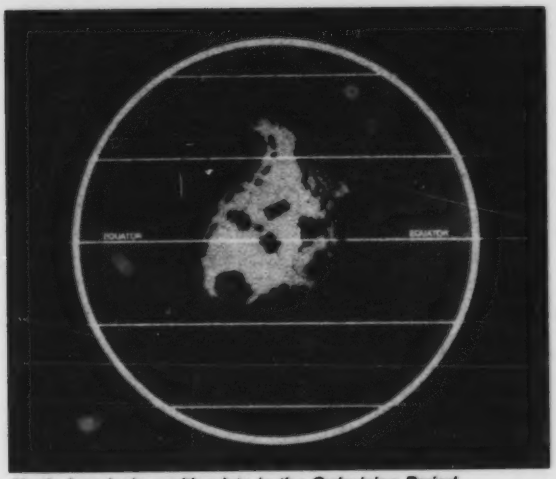
These fieldstones originated from exposures that we can still see today in the Manitoba lowlands. Rocks of the several formations that make up the Red River Group of late Ordovician and early Silurian age are exposed southeast of La Ronge, and east through the interlake area of Manitoba to Winnipeg, and again on the western edge of Hudson Bay. With the advance of the great glaciers of the Ice Age, many blocks of these limestones were scraped from the surface, frozen into the ice, and carried southwest until they melted out of the ice front.

In both the Tyndall stone we see on buildings (the most widely seen fossil display in Canada), and in our fieldstones, a variety of fossils is evident. These include the organisms that built huge carbonate banks in this area, the stromatolites that were built by cyanobacteria ('blue-green algae'); and huge groupings of encrusting bryozoans, or



Fossils in Tyndall Stone.

'moss animals.' Huge reefs built by colonial corals did not appear in this area until later on in the Silurian, though reefs do appear in the Ordovician of New York State. No satisfactory explanation for this distribution has been advanced, but the cause may have to do with the continent's position at that time: Saskatchewan and Manitoba were very near the equator, and New York was some distance to the south.



North America's position late in the Ordovician Period.

Also important, and highly visible in Tyndall stone, are the sedentary animals that lived in the carbonate banks and at their edges. Corals, both solitary forms like the horn corals and colonial corals that lived in small (up to a metre diameter) colonies, are very common. These colonial corals included tightly-packed colonies, branching forms, and the curious 'chain corals,' typified in Ordovician deposits by *Catenipora*.

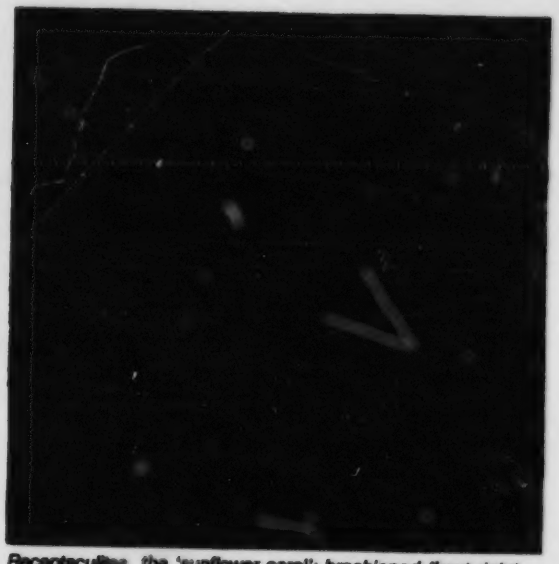
Also attached to the bottom were stromatoporoids, the crinoids or 'sea lilies,' and the brachiopods, or 'lampshells.' Though crinoids are commonly seen in building stone, only cross-sections of stromatoporoids and brachiopods usually appear, and these are not easy to identify.

Not attached to the bottom, but performing all their activities there, were early clams and snails, starfish and their relatives, and trilobites. Floating on the surface, and virtually never seen in local limestones, were graptolites, jellyfish, and a variety of microscopic organisms.

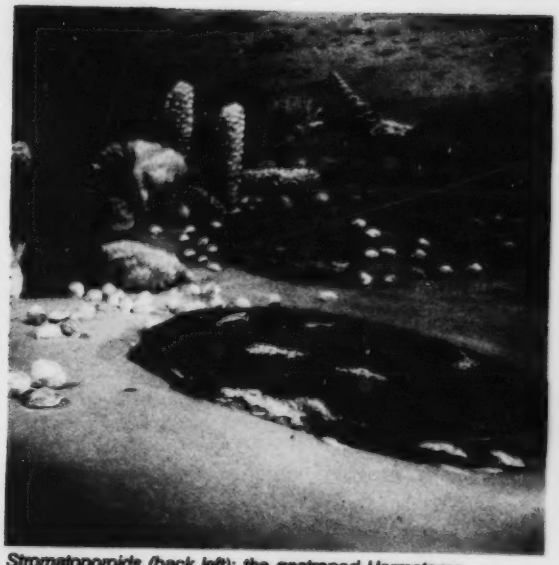
Free-swimming animals included the ostracods (Ordovician leperditiids were among the largest in the group's history, and are known from our rocks) and a large variety of nautiloids, the predators of the time. These nautiloids include a variety of animals distantly related to today's squid and pearly nautilus, and commonly appear as straight or slightly curved or sausage-shaped individuals. Sometimes we see the entire shell, and sometimes only the siphuncle or gas tube of the interior. These nautiloids were the major free-swimming predators. With a head and tentacles like a squid, they were able to feed either on the bottom or in open water.

Also free-swimming but spending most of their time feeding at the bottom, were very early fish. The earliest known fish are from late Cambrian rocks. No fossil fish have been found in our Ordovician-Silurian rocks, but plates from the head shields of several kinds of jawless fish are known from Colorado, Ontario, and many other areas.

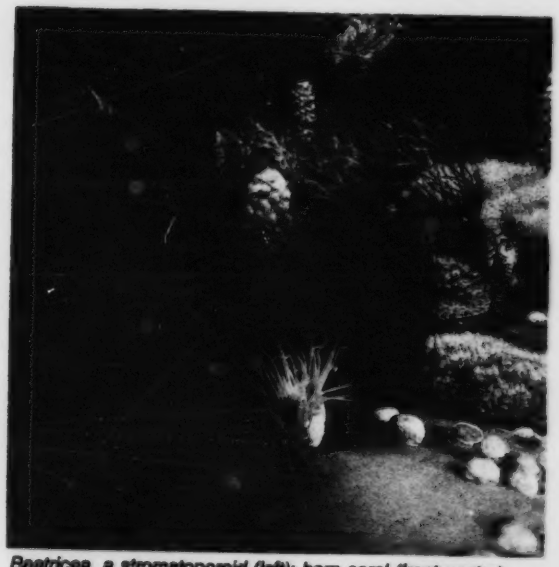
Crinoids.



Receptaculites, the 'sunflower coral'; brachiopod (front right).



Stromatoporoids (back left); the gastropod Hormotoma (back center); colonial corals (front, center, and back right).



Beatricea, a stromatoporoid (left); horn coral (front center); brachiopods (front right).

Our early fossil record, and that of most of the rest of the world, appears to be made up only of hard-shelled organisms of relatively familiar types, and seems to represent a relatively simple ecosystem. Large, free-swimming organisms are particularly poor in diversity. Nevertheless, experience shows that there may have been many soft-bodied organisms that could be preserved as fossils only under special conditions, and the mid-Cambrian Burgess Shale fauna of Field, B.C. provides an interesting example. We must always remember that most of the extinct flora and fauna may be preserved only under unusual conditions.

The Ordovician environment, except for its lack of the coral reefs that became prevalent later, is typical of the early shallow seas of Saskatchewan, and we have used it to interpret a very long segment of time. These shallow seas near the equator featured warm water, that was clear enough for light to penetrate to the coral polyps and to the algae and bacteria that formed stromatolites. A huge area of ocean covered most of the interior of North America, and this ocean was shallow because it was sitting on the low interior of the continent rather than in deeper ocean basins. Thus the Palaeozoic of the North American interior is extremely rich in marine fossils preserved in limestones, and our story is also typical of the interior of North America.

Limestones of the Red River Group are extensively dolomitized: altered by addition of magnesium ions to form a harder carbonate

mineral, dolomite. Dolomitization is most extensive and noticeable in a network of dark lines that run through the rock. These lines are the paths or burrows of small organisms, assumed to be marine worms, that honeycombed the sediments. Today we see only traces of the burrows, which are usually a dark gray, and stand up to weathering better than the rest of the rock, so that we often see them as slightly raised areas in the stone. Depending on the local extent of burrowing, dolomite often surrounds or enters the fossils themselves.

The ocean in which Tyndall stone was formed.

Another geological story that begins in the Ordovician Period is that of the Williston Basin (p. 17). Possibly beginning as a smaller fold in the Western Canada Sedimentary Basin, and continuing as an area of unusual density in the mantle, the Williston Basin sank extremely gradually but still more quickly than in surrounding areas. As a result, deposits are far thicker in the Williston Basin than in the remainder of the Western Canada Sedimentary Basin. The development of the feature continued until 50 to 55 million years ago.

Silurian Period

The next geological period, the Silurian, featured conditions very similar to those of the Ordovician. Only rocks of the earliest Silurian (the last of the Red River Group) are exposed in Saskatchewan, but most of the period is represented by limestones of the Interlake Group in the subsurface.

Silurian rocks have been studied rather little in Saskatchewan. Some oil staining occurs, but no commercial oil fields have been found.

Devonian Period

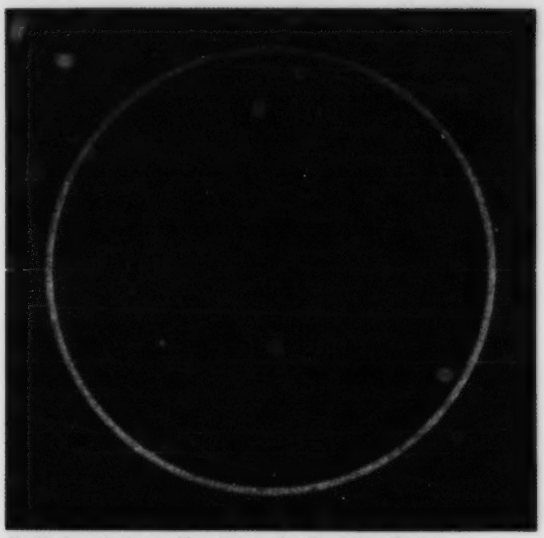
The Devonian was an important time in the development of western Canada's resources. Both the oil and potash industries depend on minerals in Devonian rocks.

The early Devonian appears to have been a time of erosion and possibly of emergent land. No rocks of this age are known from our area.

During the middle Devonian we know of many massive coral reefs throughout the Canadian Plains, and for many years Alberta's oil industry has depended on oil fields held within these reefs. Only recently have massive pinnacle reefs of the Winnipegosis Formation, perched on older

Abundant life in the late Ordovician sea.

Ordovician



North America's position late in the Devonian Period.

carbonate banks of southeastern Saskatchewan, been tapped. These Winnipegosis reefs promise to produce huge quantities of oil, with much higher rates of flow than are known in our province's other oil reservoirs. In the gallery's block model, a Winnipegosis pinnacle reef appears on the east side, near the province's southeastern corner: these reefs are large enough to show, even at 1:2500 scale.

Immediately on top of the Winnipegosis carbonates, forming a cap to trap petroleum in the reefs, are the salt, anhydrite, and potash of the Prairie Formation. These atypical beds originated in a restricted basin that formed, collected evaporite deposits during about two million years of mid-Devonian time, then opened again to normal ocean circulation.

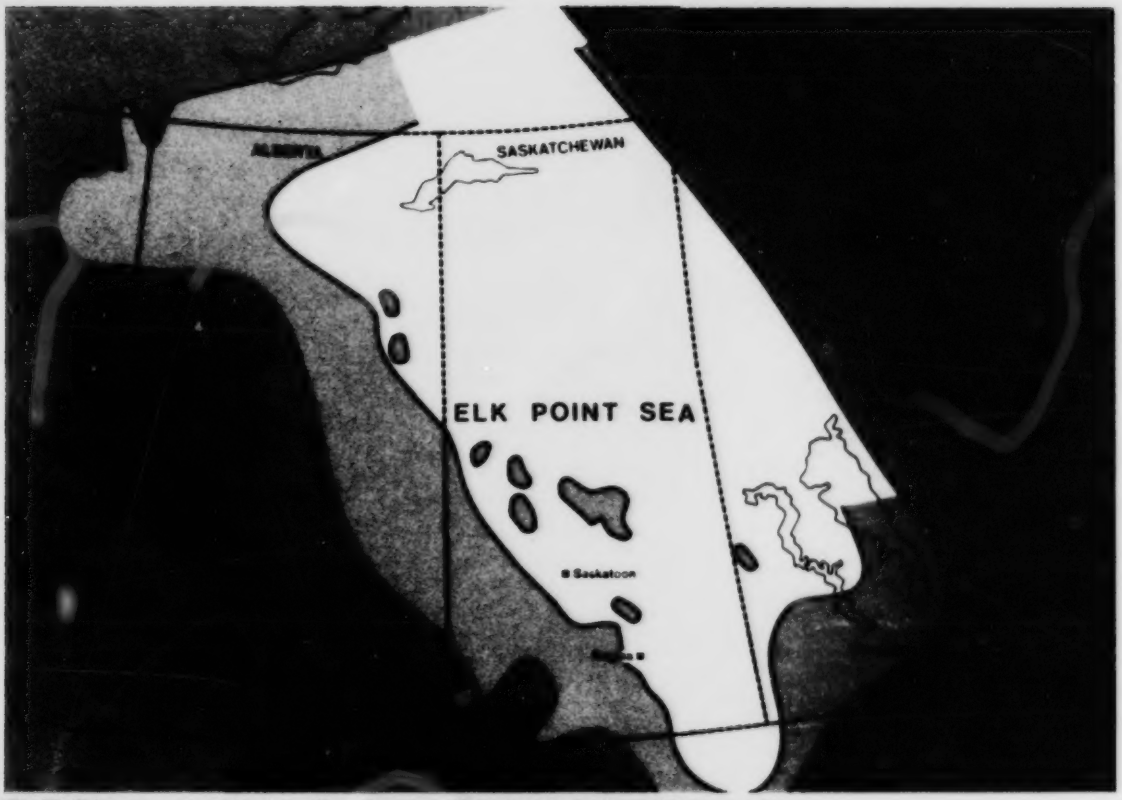
This Elk Point Sea was between the high grounds of the Swift Current Platform, Alberta Ridge, and Peace River Arch to the west, and the massive Ordovician-Silurian carbonate banks of the Red River and Interlake Groups to the east. Exchange of water with the open oceans to the north and northwest was interrupted from time to time, as indicated by layers of salt and anhydrite in northern Alberta and northern Saskatchewan, but a significant time of free circulation is indicated by the success of Winnipegosis reefs, which attain thicknesses of 150 metres.

A particularly massive reef (150 to 200 metres thick) in the northwest (approximately along the Alberta-Northwest Territories boundary), the Presqu'ile Reef, extended eastward to the present area of Great Slave Lake, where it blocked off the only open side of the Elk Point Sea. It is important to realize that the reefs and banks that restricted this sea did not, for the most part, stand above the ocean as dry land, but merely blocked circulation at middle and deep levels. Thus when water evaporated from the surface (and evaporation rates were high near the equator), normally saline surface water flowed in from the adjacent oceans, but increasingly saline water within the basin was not free to leave via bottom currents.

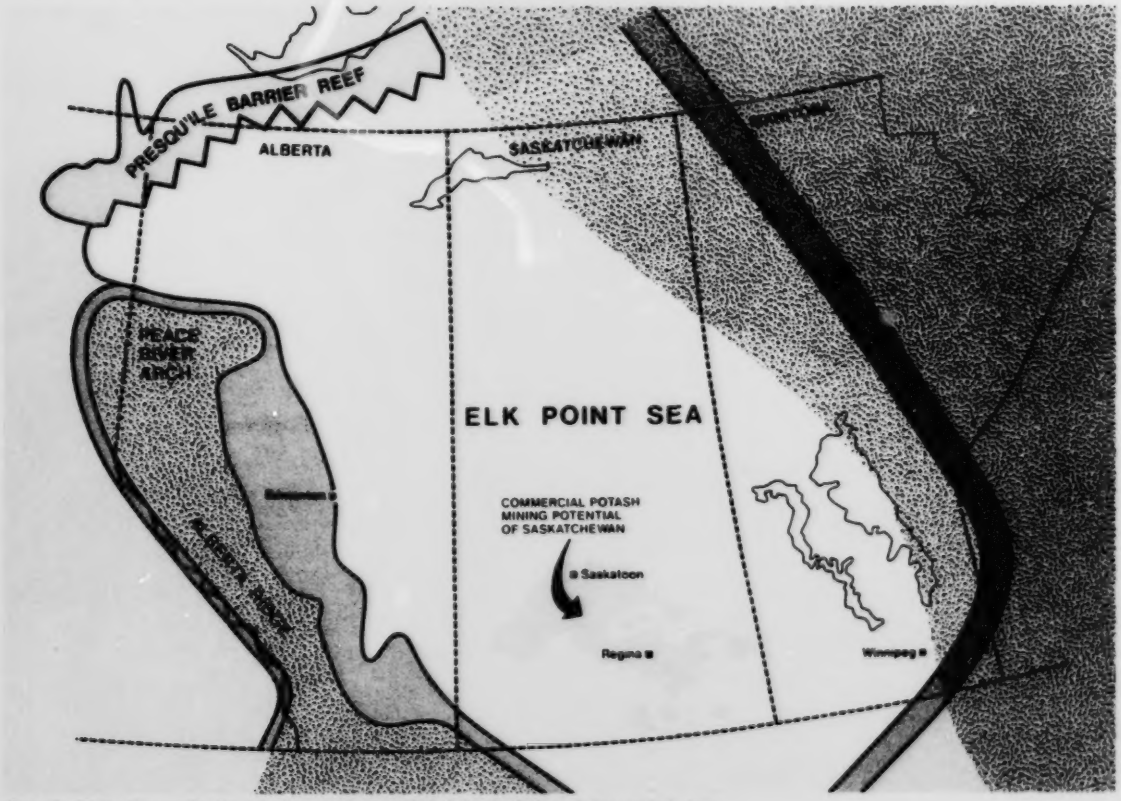
Eventually the water of the Elk Point Sea became so saline that mineral salts began to precipitate out of solution and collect at the bottom. Salts that

The lifeless potash sea.

Devonian



The Elk Point sea was restricted on three sides by reefs, carbonate banks, and high grounds.



Growth of the Presqu'ile Reef in the north completed the isolation of the potash sea.

are the least soluble precipitate out first, and anhydrite (rock gypsum) is common at the base of the Prairie Evaporite and throughout the basin. Halite (rock salt) precipitated next, and is the most common mineral in the basin, predominating in halite-anhydrite beds up to 300 metres thick. Potash, a mixture of minerals of which sylvite and carnallite are the most common, precipitated last and is present only in the top 60 metres of the Prairie Formation, and only in southern Saskatchewan, southwestern Manitoba, and northernmost North Dakota. These areas represented the most restricted portions of the basin, at the maximum concentrations of mineral salts.

Today potash is mined by conventional room and pillar methods down to about 1000 metres below the surface, and by injection of hot water (solution mining) beneath that depth.

After the deposition of the Prairie Formation, the Presqu'ile Reef was breached by erosion, and normal ocean circulation resumed. Shales and limestone-dolomite beds overlie the evaporites, and the basin was never again restricted enough for salt or potash deposition, although anhydrite beds are known sporadically into the early Carboniferous. These anhydrites are assumed to have formed in isolated troughs within the ocean basin.

Devonian seas before and after evaporite deposition contained abundant life. The Devonian is noted for its diversity of fossils including abundant corals, huge armored fish, the 'sea scorpion' eurypterids, and one of the first extensive land-living communities including insects, large land plants, and the first amphibians, but we know of no fossils at all from the Prairie Evaporite. Probably no large plants or animals lived here because of the high salinity.

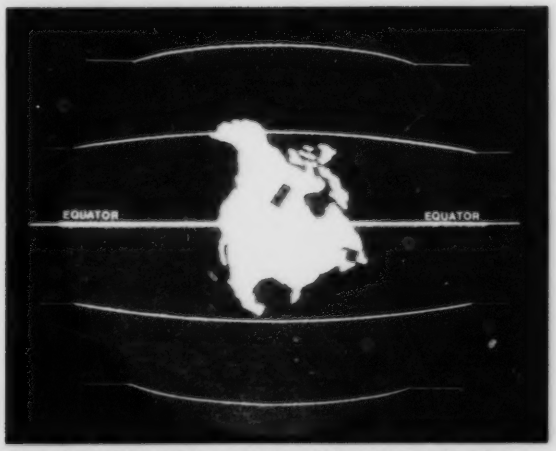
In very salty landlocked lakes of today (the Dead Sea and lakes in Death Valley) and in coastal lakes where water comes from seawater seepage (Laguna Mormona, Baja California), very little life occurs. In the most salty modern environments, living things include only small, hard shelled organisms like brine shrimp, which can exclude the saline water from their bodies: otherwise they would lose all their body fluids to the sea water. Scientists presume that the situation was the same during the mid-Devonian.

The Elk Point Sea of western Canada was not the only restricted basin of the Palaeozoic Era. To the east of us, the Michigan Basin, which covered nearly all of the lower peninsula of Michigan and parts of Indiana, Ohio, and Ontario, preserves massive deposits of salt and anhydrite of Silurian age, and several other restricted basins of Silurian to Carboniferous age are known in North America.

The later Devonian deposits of Saskatchewan are made up of limestone and dolomite, with anhydrite beds common in some intervals. These Souris River, Saskatchewan Group, Torquay, and Big Valley beds are not exposed at the surface, and Devonian rocks crop out only in the La Ronge and Clearwater River areas, where the Winnipegosis, Contact Rapids, and La Loche Formations are found in limited exposure.

The beginning of tectonic activity in the Rocky Mountains is also notable, and the Devonian saw the start of mountain-building activity that continues today.

Carboniferous Period



North America's position near the middle of the Carboniferous Period.

The Carboniferous Period is broken up into the Mississippian and Pennsylvanian Periods of American terminology. A variety of formations of early Carboniferous (Mississippian) age are buried deep in the basin, and never are exposed at the surface. We have no late Carboniferous (Pennsylvanian) rocks in our province.

Carboniferous limestones composed of fragmentary fossils are capped by anhydrite beds in southeastern Saskatchewan, forming oil traps that have been important reservoirs in the Weyburn-Midale-Estevan area, and near Parkman and Wapella. These limestones contain large reserves of oil and gas, but the pores in the rock are often small and poorly connected, so hydrocarbons seep slowly through the rocks and the wells produce only slowly.

Our Carboniferous rocks have produced many fossils, particularly corals, brachiopods, snails, and clams. One partial fish has been found, but can be identified only as a palaeoniscoid.

At the base of our Carboniferous section is the Bakken Formation, an oil shale which is an important source rock. Within this shale are trapped masses of microscopic plants and animals. When accumulation of sediments in the Western Canada Sedimentary Basin was at its maximum, probably in mid-Tertiary time or slightly earlier, sufficient heat and pressure built up in the Bakken, which was then buried at least 1600 metres deep (as opposed to today's 600 to 650 metres) to form hydrocarbons. Tiny plants were converted into oil, while microscopic animals mostly became natural gas. The Bakken and its equivalents occur under most of the Great Plains of North America.

Permian Period

No Permian deposits occur in Saskatchewan, and presumably the entire time from the end of the early Carboniferous to the Triassic was one of emergent land, and erosion. The Permian worldwide was a time of low sea levels, extensive emergence of land, and terrestrial conditions that have been interpreted as very dry. Red deposits that are presumed to have been deposited in near-desert conditions occur from Prince Edward Island to Texas. The nearest Permian rocks to us are in the Rocky Mountains of Alberta and British Columbia.

At the end of the Permian, the earth's greatest extinction occurred. More than 90 per cent of living species became extinct 248 million years ago. Many primitive groups of plants perished, including the scale trees, and seed ferns became scarce. The rise of the coniferous trees and primitive cycads probably contributed to this floral turnover. Beetles originated late in the Permian Period, and a great variety of primitive reptiles and amphibians carried on relatively undisturbed into the succeeding Triassic Period, the earliest period of Mesozoic time.

It was among marine invertebrates that Permian extinction took its greatest toll. Most ammonoids and brachiopods died out, but the few survivors began new radiations in diversity. Ammonoids underwent another mass extinction at the close of the Triassic Period, and finally became extinct at the close of the Cretaceous Period, while some few brachiopods survive today and the group is much less diverse than it was during the Palaeozoic Era. Fusulines, trilobites, honeycomb corals, tetracorals, most crinoids, all blastoids, and two orders of bryozoans became extinct.

The Permian Period was a time of low water levels in the ocean basins, and great reduction of the world's epicontinental seas (those seas that result from flooded continental land masses). The greatly reduced, and changed, habitat for marine invertebrates probably led to their crash in diversity at the end of the period, though some paleontologists think that a sudden, violent mass extinction had an extraterrestrial cause.

CHAPTER 4

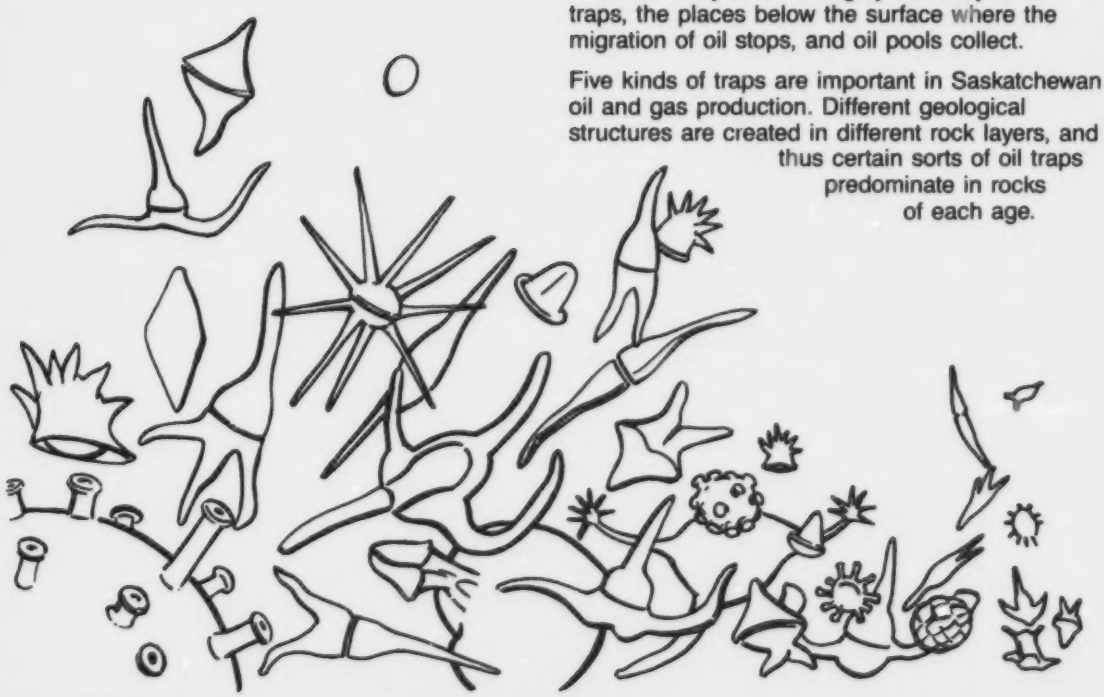
The Story of Oil

Oil and gas originate from the remains of microscopic plants and animals, and in some instances like the Carboniferous Bakken Formation mentioned earlier, we can observe petroleum still in place in the oil shales where it formed.

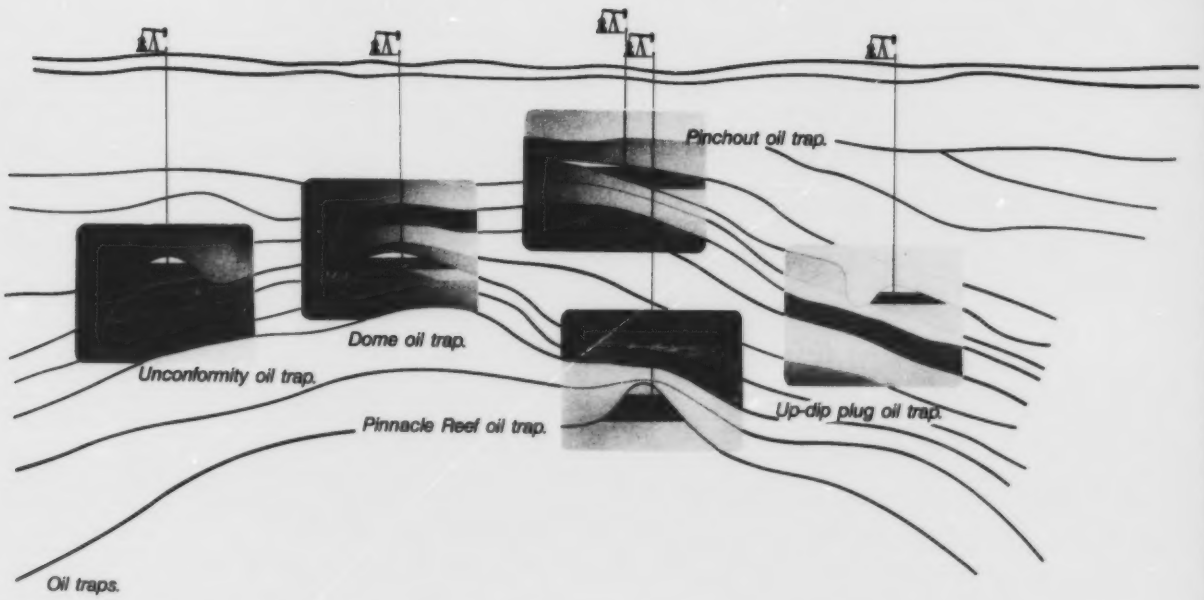
Most oil and gas, however, migrates from the place where it was formed, and is found in porous rocks that are buried less deeply. Petroleum seeps upward along faults and through permeable rock layers, away from the high temperatures and pressures at which it was created. It continues to move until it is trapped by a layer through which it cannot flow, or until it cools and comes to equilibrium.

Thus the story of oil is largely the story of oil traps, the places below the surface where the migration of oil stops, and oil pools collect.

Five kinds of traps are important in Saskatchewan oil and gas production. Different geological structures are created in different rock layers, and thus certain sorts of oil traps predominate in rocks of each age.



Microscopic organisms typical of those that formed oil and natural gas.



Oil traps.

A **pinchout** traps oil and gas where a layer of reservoir rock ends suddenly, leaving only impermeable rock through which nothing can flow. Pinchouts are common in Cretaceous rocks of western Saskatchewan, where sandstone layers reach the limits of their deposition, giving way to dense marine shales that formed farther offshore. The heavy oil of the Lloydminster area, and the conventional oil and gas of the Kindersley and Hatton areas are trapped in pinchouts.

A large, isolated reef growing on the high ground of a carbonate bank is called a **pinnacle reef**. Pinnacle reefs have long been important in the Alberta oil industry, but only recently have rich strikes been made in the Devonian reefs of southeastern Saskatchewan. The limestones within the reef may hold huge quantities of oil and gas, sealed in by a salt or anhydrite caprock.

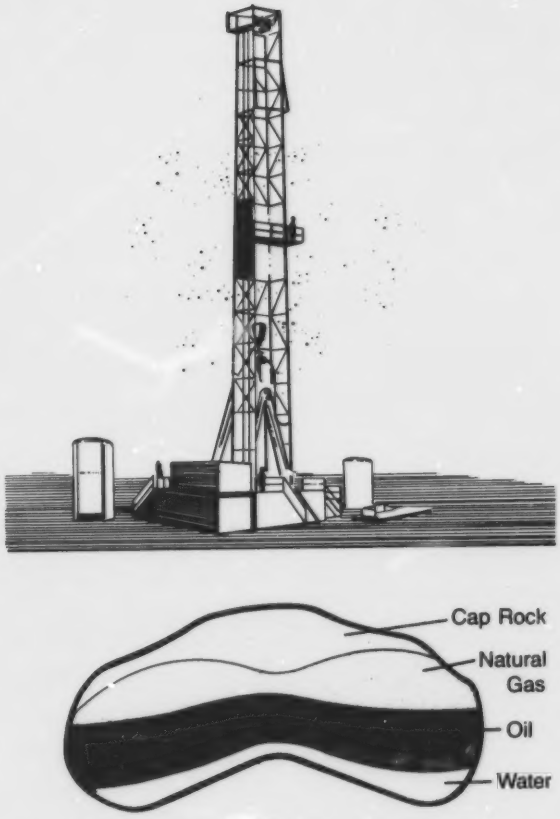
A **dome**, or anticline, forms when rock layers are pushed up, long after their deposition, into an arch. Gas and oil may be trapped at the top of the arch in reservoir rock if a cap of impermeable rock lies above. Domes may form because of the sideways pressures from mountain-building, or because of partial collapse and shifting of deeply buried salt beds. Saskatchewan's domes are major sources of petroleum in Carboniferous rocks of the southeast and Cretaceous rocks in the west.

An **unconformity** is a break in the depositional sequence of rocks. If the underlying beds were tilted, eroded, and then covered with flat-lying impermeable rocks, then oil and gas may be trapped at the unconformity. In Carboniferous rocks of southeastern Saskatchewan, unconformity traps are very important sources of petroleum.

An **up-dip plug** may block the upward flow of petroleum in an otherwise excellent reservoir rock. The plug is formed when impermeable muds are deposited in channels cut through a lower reservoir layer, forming a barrier or dam. As a result, parts of the reservoir may hold only water and no gas or oil. These traps occur in Cretaceous oil and gas fields of western Saskatchewan, and are a complicating factor in petroleum exploration.

An oil and gas 'pool' is not a lake held in an underground cavern, as the name implies. Instead gas, oil, and water occupy the pore space in sedimentary rocks like sandstone or limestone. These pores need not be large, and may not even be visible without magnification. What matters is that the pores are well connected to each other, so that gas, oil, and water can pass through freely.

In our gallery a double-stand drilling rig is shown above an idealized oil pool. The double-stand rig, named because two standard lengths of drilling pipe fit between the drilling platform and the crown block, or top pulley, is seen most commonly in Saskatchewan oil fields. A double-stand rig bores holes up to 2100 metres (nearly 6900 feet) deep. For deeper holes up to 3200 metres deep, a triple-stand rig is employed.



Double-stand drilling rig and a typical oil and gas pool.

Mesozoic Era

CHAPTER 5

The Mesozoic Era, the time of 'middle life,' was the transition between early, unfamiliar plants and animals and a much more modern assemblage. Early in this era the coniferous trees displaced many of the tree ferns. Then near the middle of the Cretaceous Period the flowering plants originated, quickly became dominant in many environments, and added such familiar trees to our landscape as sycamore, elm, beech, and magnolia.

The last two classes of vertebrates, the birds and mammals, originated during the Mesozoic Era, and so did the dinosaurs, which some scientists classify as reptiles and others allocate to a separate class. Although dinosaurs dominated the scene, by the end of the Mesozoic Era many plants and animals existed that would be familiar to us today. Most modern orders of insects also made their appearance during the Mesozoic, including caddis flies, scorpion flies, dragonflies, grasshoppers, termites, moths, true flies, and ants.

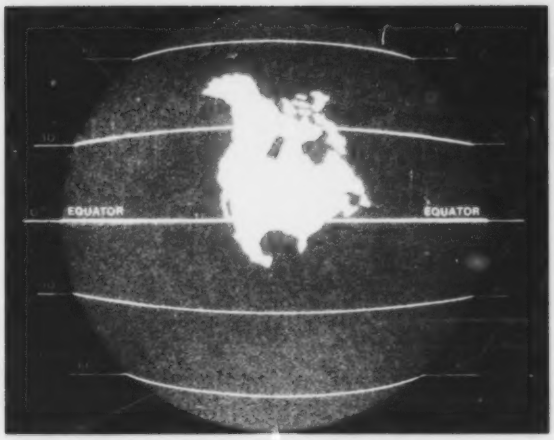
In the oceans, the modern families of reef-building corals originated, and oysters appeared. Ammonoids, having nearly become extinct at the end of the Palaeozoic Era, were diverse and common, although a wave of extinctions near the end of the Triassic Period nearly eliminated them.

In Saskatchewan, the late Palaeozoic Era and the Mesozoic Era were the time of movement, because of continental drift, from the tropical and near-tropical regions that our area had occupied from very early in our geological history, to more northern latitudes where cooled ocean waters predominate and the coral reefs and other familiar bottom-dwellers of the tropics do not live.

By the end of the Mesozoic, the sea withdrew completely from Saskatchewan. On our newly emergent land, increasingly dense forests grew, inhabited by a great variety of animals including dinosaurs. Thus the Mesozoic Era not only was the time of a complete change in the character of

the shallow seas that had dominated Saskatchewan for hundreds of millions of years, but also saw their disappearance. The Mesozoic was an important time of transition in our area.

Triassic Period



North America's position late in the Triassic Period.

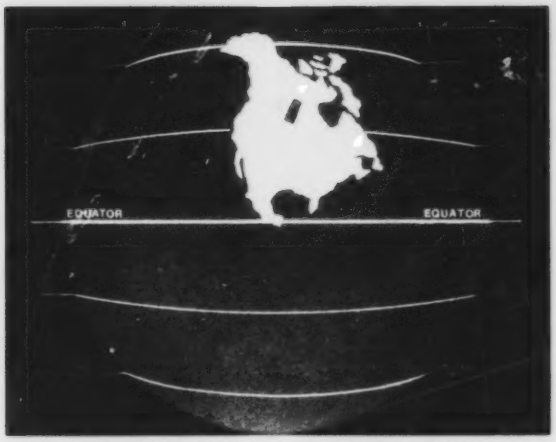
Some poorly known, deeply buried beds, the 'Lower Watrous' Formation, represent the last part of the Triassic Period. These deposits are redbeds, probably formed in river valleys, under generally dry conditions. Unfortunately, no fossils are known from Saskatchewan to tell us what sorts of plants and animals lived here early in the Mesozoic.

The Triassic Period was the time of origin of the dinosaurs 245 million years ago, and after a rapid diversification of therapsids, the 'mammal-like reptiles,' around 230 million years ago, the first representatives of our own Class Mammalia came on the scene 220 million years ago. If our late Triassic redbeds were exposed, we might find some of these first mammals in them, as paleontologists do in the southwestern United States, China, and other areas.

A recent discovery in west Texas has been identified as the earliest known bird. If this claim is confirmed, it would date from a period earlier than *Archaeopteryx*, formerly the earliest avian.

Jurassic Period

Thick layers of Jurassic limestones, dolomites, shales, and sandstones are buried in the subsurface of Saskatchewan. These rocks of the Watrous, Gravelbourg, Shaunavon, and Vanguard Formations are not exposed at the surface, and are normally encountered only in drill core. Some artificial exposure has been created in the shafts of potash mines.

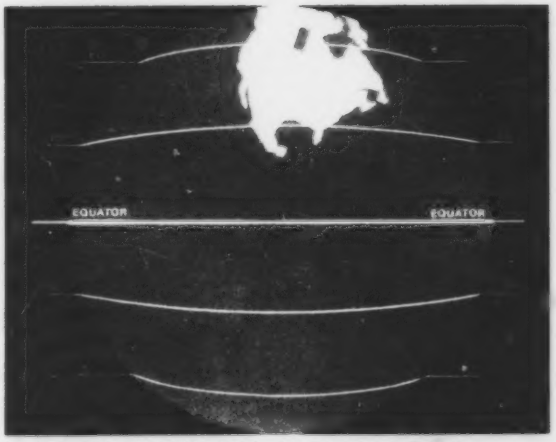


North America's position late in the Jurassic Period.

Limestones of the Shaunavon Formation and sands of the middle Vanguard Formation produce oil in the Swift Current area. Flow rates of these wells are usually low.

Jurassic rocks of Saskatchewan were formed under marine conditions, and have produced abundant brachiopods, corals, ammonoids, snails, and clams, and some fragments of fish. More recently, core from a well east of the Great Sand Hills yielded a jaw fragment of a fish that appears to have been a very early relative of *Amia*, the bowfin.

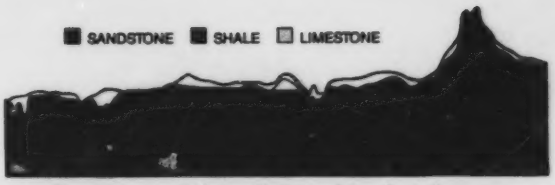
Cretaceous Period



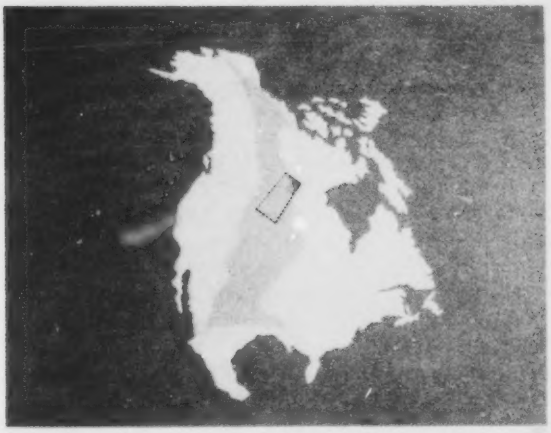
North America's position late in the Cretaceous Period.

The Cretaceous is one of the longer periods of geological time, lasting 79 million years. This period is of major interest for its fossils, which abundantly represent the plants, invertebrates, and vertebrates of both the sea and land, and for its natural resources, which include oil and gas through the western plains, and increasing quantities of soft coal in Alberta.

Nearly all of the Western Canada Sedimentary Basin preserves deposits of Cretaceous age. The only areas where older (Palaeozoic) beds appear at the surface are at the edge of the Canadian Shield, where erosion has cut down to Ordovician, Silurian, and Devonian formations.



Late Cretaceous rocks beneath the surface of southwestern Saskatchewan. Sands indicate shorelines building from the west, shales show invasions of the sea from the southeast.



The Western Interior Seaway late in the Cretaceous Period, about 80 million years ago.

The Western Interior Seaway covered Saskatchewan during most of the Cretaceous Period. Through most of this time, and perhaps as late as 70 million years ago (early Maastrichtian Stage) the seaway connected the Gulf of Mexico with the Arctic Ocean, running north-south (present direction) from Banks Island to eastern Mexico.

The extent of the Western Interior Seaway was probably determined by worldwide sea levels, but as time went on it tended to have a progressively more eastern course. With the onset and intensification of the Laramide Orogeny, land began to build eastward from the rising Rocky Mountains. With each regression of the sea, more and more land was exposed, at first only into eastern Alberta as reflected in the near-shore sandstones (oil sands) of the McMurray Formation and Manville Group, deposited nearly 105 million years ago. Then the Milk River Formation formed a shoreline reaching into southwestern Saskatchewan about 80 million years ago. The Judith River shoreline reached as far east as Regina about 75 million years ago. The final regression represented by the Frenchman Formation was the final retreat of the sea from Saskatchewan about 66 million years ago.

Invertebrate faunas occur throughout the marine deposits, including spectacular ammonoids. These cephalopod molluscs, distantly related to the modern squid, octopus, and pearly nautilus, occur in great taxonomic diversity, and in corresponding diversity of form. Ammonoids of various families, especially the baculitids, are key fossils that paleontologists use to 'tell time': different species characterize different-aged strata, and by identifying the ammonoids within a deposit of unknown age, the scientist can correlate the fossils with known points, and dates, in the stratigraphic sequence elsewhere.

Other important marine molluscs are the clams (bivalve, or pelecypod molluscs). Characteristic forms include oysters, and range from the large *Inoceramus* down to tiny forms. Gastropods appear as snails and limpets. The solitary coral *Micrabacia* has been reported from a few localities, but it is rare, presumably because the water of the Western Interior Seaway was rarely clear enough for corals to survive. No reef-building

Land emerged several times as the sea withdrew late in the Cretaceous Period. Low beaches, islands, and gradually-sloping shorelines prevailed.

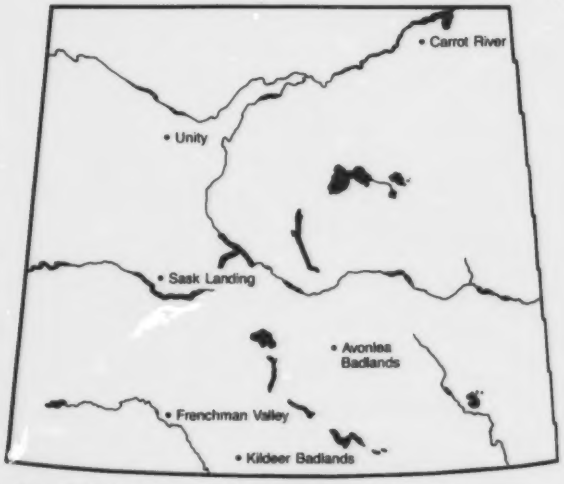
corals lived in this northern sea. Scaphopods (*Dentalium*) are known, and so are crayfish. The inarticulate brachiopod *Lingula* is widely represented. Fossil plants are not known from the marine Cretaceous of our area.

Cretaceous marine deposits are shales and sandstones, reflecting the bottom conditions of the time. Studies have found that among the sessile and bottom-feeding forms (clams, oysters, *Lingula*, *Dentalium*, snails), the animal communities show distinct preferences for different substrates (silty sands, silts, sands, clayey silts) that represent near-shore to offshore environments. The free-swimming predators among the ammonoids and nautiloids are more generally distributed.

Vertebrates are also found in the marine Cretaceous of Saskatchewan, although they have been studied inadequately to reflect their real diversity.

The earliest of our Cretaceous vertebrate faunas occurs in Colorado Group (probably Niobrara Formation) sediments near Carrot River. The fossils are about 90 million years old, and represent nine species of cartilaginous fish (sharks, rays, etc.), bony fish, turtles, and marine reptiles (mosasaurs and plesiosaurs). The fossil vertebrates occur in great numbers at two or more localities, in a sequence of black shales with layers of calcite 'beef,' and possibly a layer of volcanic ash. Invertebrates are uncommon, but oysters and the marine clam *Inoceramus* are found there.

Although scraps of vertebrate material are known from many areas, the next considerable assemblages of marine vertebrates are from the Bearpaw Formation, a series of shales about 68 to 71 million years old. We know that considerable faunal change occurred among the invertebrates during the two to three million years that elapsed during Bearpaw deposition. Because not all fossiliferous localities have been collected properly and most of the fossil vertebrates have not been studied, it is difficult to determine what was happening among the vertebrates, but we suspect that significant change was also occurring in those groups.



Major collecting areas for fossil vertebrates of the late Cretaceous Period.

Mosasaurus conodon, a 10-metre-long mosasaur of the late Cretaceous seas (center); an elasmosaur, or long-necked plesiosaur (left).

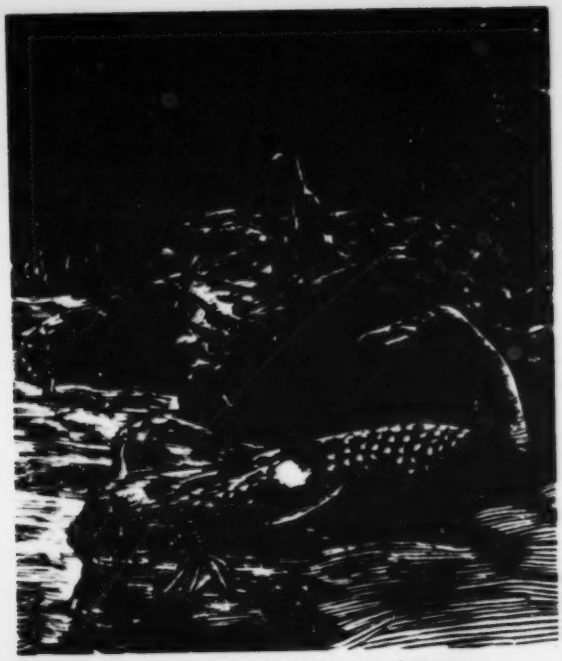
In localities along Lake Diefenbaker, ranging at least from Saskatchewan Landing Provincial Park to Riverhurst, and in the Avonlea Badlands near Regina and Moose Jaw, isolated bones and sometimes partial skeletons of mosasaurs and plesiosaurs have been found. The mosasaurs, which attained lengths up to 10 metres in our area, were closely related to the lizards. They swam by forcing the laterally-flattened tail back and forth and steering with their front and rear flippers. Mosasaurs were highly streamlined, and they must have been very quick and agile as they chased after the fish and swimming molluscs that were their prey. Mosasaurs are known to have hunted and eaten ammonoids, and specimens of the large, dish-shaped *Placenticeras* occur with mosasaur tooth marks in the shell.

Plesiosaurs, some of which (the elasmosaurs) had extremely long necks, were entirely differently proportioned. These swimming reptiles are of uncertain relationships, although it is known that they were descended from land-dwelling reptiles.

Both pliosaurs (the short-necked kinds) and elasmosaurs powered their swimming with their huge flippers, and swam after fish and shellfish. Although the plesiosaurs were heavier-bodied than the mosasaurs, and were probably not as agile, they were extremely powerful swimmers and could likely swim at high speed for a longer time. They reached lengths of 10 metres or more in Saskatchewan.

Bony fish are uncommon in our Bearpaw Sea, with teeth of *Enchodus* and isolated scales making up most of the specimens. Among the cartilaginous fish, shark teeth have been reported from the Riverhurst Ferry area, and teeth that may represent ratfish (chimeras) are known from Main Centre. Scraps of marine turtle have also appeared.

To date, remains of the toothed diving birds of the late Age of Dinosaurs are not known from our marine deposits, nor are the gliding reptiles or pterosaurs. The flightless bird *Hesperornis* has



Ichthyornis, a toothed diving bird of the late Cretaceous Period.

Hesperornis, flightless, toothed diving bird of the late Cretaceous Period.

been collected from both Manitoba and Alberta, and *Ichthyornis* is known from the Northwest Territories. These divers, whose legs were set far back on the body as in the modern loon or cormorant, certainly existed here, and so did the gliding, fish-eating pterosaurs. There are now several pterosaur records from Alberta, including bones that are assigned to the huge *Quetzalcoatlus*, which had nearly a fifteen-metre wing span.

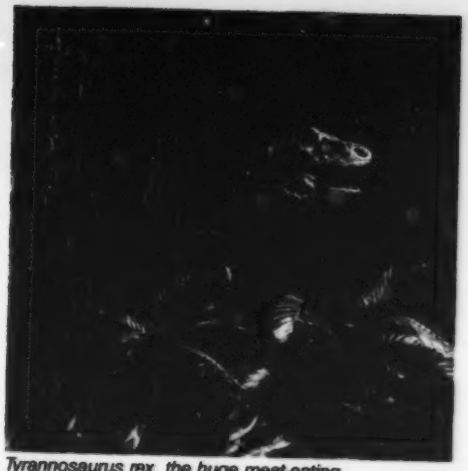
An interesting oddity from the marine shales of our Bearpaw Sea is a partial skeleton of a duck-billed dinosaur from badlands near Main Centre. Although the dinosaurs are not known to have been aquatic and may have spent very little time in the water, this large, flat-headed duckbill (possibly *Edmontosaurus* or a close relative) floated out to sea and sank to the bottom before decomposing. It probably floated almost 500 kilometres, and the closest land at the time was near present-day Edmonton. Scraps of horned dinosaur (ceratopsian) bone have also been found in the Bearpaw Formation of Saskatchewan. About 95 other dinosaur records from marine sediments are known from Montana to Baja California, and along the East Coast. Most of these other records are of duckbills, like the Saskatchewan occurrence.

There is no record of the plants of the Cretaceous sea, although carbon found in the shales may represent plant remains.

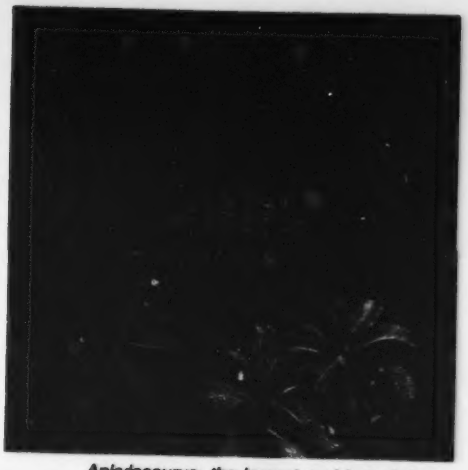
On the land, a great variety of plants and animals lived. The proliferation of angiosperms in the mid-Cretaceous nearly brought the ancient tree ferns to extinction, cut down on the dominance of cone-bearing plants, and brought into existence a number of familiar-looking trees including sycamore, magnolia, beech, oak, and maple. These lived in a mixed, mostly closed-canopy forest with sequoia, pine, ginkgo, palms, cycads, and, in low areas, cypress. The mixed deciduous-coniferous forest was not of a type seen in this area today, and has no exact modern equivalent, but is most comparable to forests of the southeastern United States or Southeast Asia. These floras and faunas of the Frenchman Formation represent the last 1.6 million years of the Cretaceous Period (Lerbekmo, 1987), and a wide assortment of plants but no vertebrates, is found in the slightly earlier Whitemud Formation.

A limited vertebrate fauna is known from south of Unity. Dinosaurs, fish, and lizards have been recovered, apparently equivalent to the 75-million-year-old assemblage at Dinosaur Provincial Park, southern Alberta. *Albertosaurus*, *Troodon*, *Saurornitholestes*, *Dromaeosaurus*, *Monoclonius*, duckbills, and bird mimics are currently known from Unity.

Latest Cretaceous dinosaurs (Frenchman Formation) of our area include the saurischian (lizard-hipped) dinosaurs cf. *Dromaeosaurus*, *Troodon*, *Ornithomimus*, and *Tyrannosaurus*. All these except *Ornithomimus* had sharp teeth with serrated shearing edges, and we assume that the



Tyrannosaurus rex, the huge meat-eating dinosaur, stood 6 metres (20 feet) tall and weighed up to 6.4 tonnes (7 tons).



Ankylosaurus, the largest and last of the armored dinosaurs, had a large 'club' at the end of its tail. It grew to 10.7 metres (35 feet) long.

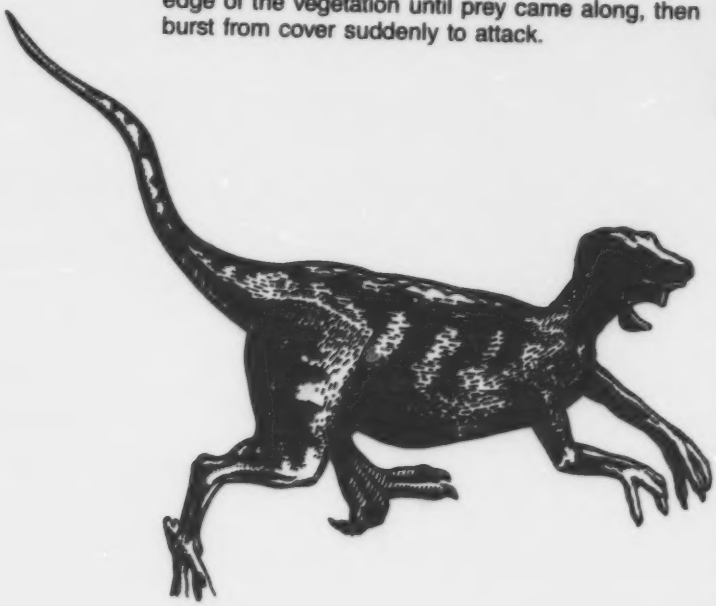
Troodon, a small, quick meat-eating dinosaur about 2.4 metres (8 feet) long.

Triceratops, one of the last and largest of the horned dinosaurs, was up to 9 metres (30 feet) long and weighed 5.4 tonnes (6 tons).

Edmontosaurus, a flat-headed duck-billed dinosaur grew up to 13 metres (42 feet 6 inches) long, and weighed 3.1 tonnes (3.4 tons).

animals were flesh-eaters and ate little or no plant material because the teeth are the right kind to slice off chunks of meat but not to grind food. *Ornithomimus* and its fellow bird-mimic dinosaurs had no teeth at all, and they are usually interpreted as scavengers. In fact, a wide range of food types was available to these dinosaurs. Eggs of dinosaurs, other reptiles and birds, carrion, live prey including smaller vertebrates (fish, amphibians, mammals) and invertebrates (insects, crayfish, etc.), and perhaps even soft fruits would not have needed chewing, and could have been part of the diet of the lizard-hipped dinosaurs.

In our diorama we interpret the behavior of *Tyrannosaurus* as comparable to that of a lion. This dinosaur may well have hidden near the edge of the vegetation until prey came along, then burst from cover suddenly to attack.

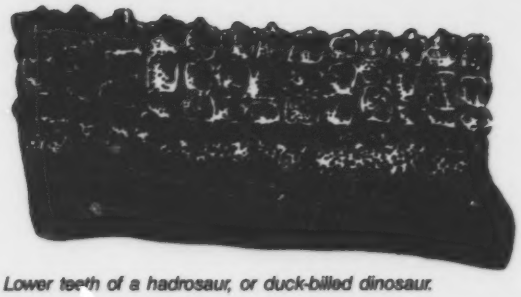


The elongated hind limbs of these saurischians, particularly the elongation of the tibia in proportion to the femur, suggests that the animals were very swift runners. Russell (1972) has suggested that the limb proportions of bird-mimics, along with their apparent thigh musculature, allowed them to run as quickly as a modern ostrich (80 km/h for up to 0.8 km), though not with the same manoeuverability.

A slightly greater variety of ornithischian (bird-hipped) dinosaurs inhabited the area, all of them apparently plant eaters.

The carnivore *Troodon* was for a time thought to be an ornithischian, but it now appears definitely to be referable to the Saurischia, according to Currie (1987).

The Saskatchewan ornithischians of the latest Cretaceous include *Edmontosaurus*, *Thescelosaurus*, *Triceratops*, *Torosaurus*, and *Ankylosaurus*. None of these has the narrow, sharp, serrated teeth required for carnivory, and all have shield-shaped or palm-shaped teeth that, to a greater or lesser degree, wore down into flat grinding surfaces for chewing plants.



Lower teeth of a hadrosaur, or duck-billed dinosaur.

Hadrosaurs, the duck-billed dinosaurs including *Edmontosaurus*, had a dental battery that formed the most complex and effective grinding mechanism of any vertebrate in geological history, including the modern ungulates. The jaws may have contained 800 to 1600 teeth, not all chewing food at once, but forming a complex arrangement two to three rows wide, with one to two extra sets of teeth positioned underneath the functioning teeth to replace them when they wore out.

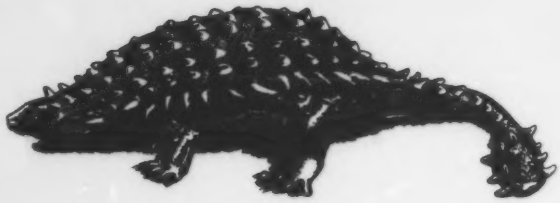
The teeth of hadrosaurs were single-rooted, shield-shaped in cross-section, and when they were unworn they were pointed at the tip. Hadrosaur teeth quickly wore to a flat surface of dentine surrounded by enamel when they came into play, and the dental battery presented a complex series of enamel ridges over which plants could be ground. The grinding surfaces of hadrosaur upper teeth are tilted toward the inside of the mouth, and the lowers are tilted toward the outside, indicating that the chewing motion was front-and-back rather than side-to-side.

Hadrosaurs also appear to have been highly-specialized social animals. Nests with eggs and young have been found in both Alberta and Montana, furnishing evidence that the duck-billed dinosaurs nested communally with many females laying their eggs in the same nest. It appears that the young remained near the nest for a considerable time, receiving protection and perhaps even feeding.

Skull of Edmontosaurus saskatchewanensis, a flat-headed hadrosaur from the Killdeer Badlands.

Ceratopsians, or horned dinosaurs including *Triceratops* and *Torosaurus*, had larger individual teeth that were two-rooted and were arranged in single rows. Ceratopsian teeth also wore into flat, shield-shaped grinding surfaces, and their orientation suggests a front-and-back chewing motion.

Horned dinosaurs were also very social, as indicated by their occurrence in 'bone beds' in several areas including Dinosaur Provincial Park, in Alberta. Each bone bed is made up of remains nearly all of which represent a single species, but the skeletons are broken and disarticulated. Scientists think that bone beds may represent the burial of herds of animals by sudden floods.

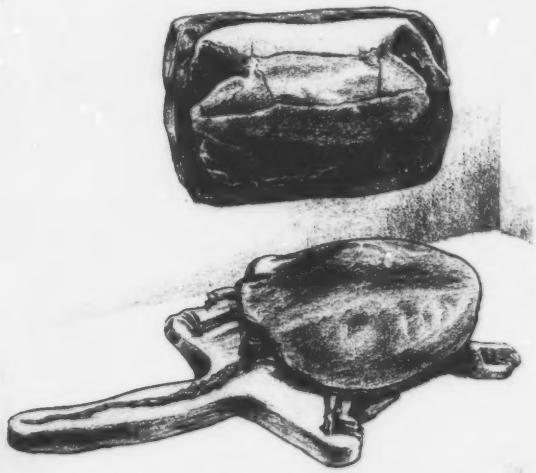


Thescelosaurus and *Ankylosaurus* were far less specialized for herbivory, and had teeth that were flattened transversely, and 'palm-shaped' in side view, with coarse, rounded lobes along the front and back edges. A low shelf occupied the interior edge of the tooth, making the base of the crown rounded-triangular in cross section. *Thescelosaurus* and *Ankylosaurus* teeth are found with wear surfaces near the tip of the crown and on the basal shelf, as if the animals had been chewing soft plant material with a back-and-forward motion of the jaws. Presumably thescelosaurids and ankylosaurids fed on much softer plants than did hadrosaurs or ceratopsians. It is obvious that their blunt-edged teeth would have been of no use in slicing flesh, and carnivory would have been out of the question.

Skull of Triceratops prorsus, the horned dinosaur, from the Frenchman Valley near Shaunavon.

Triceratops, *Torosaurus*, and *Ankylosaurus* were quadrupedal, a trait developed during their descent from bipedal ancestors.

A variety of other vertebrates shared the fresh water and the land with these carnivorous and herbivorous dinosaurs. These included fish; fresh or brackish-water rays (*Myledaphus*) and sharks (*Lonchidion*), with sawfish (*Ischyrhiza*) occurring as near as southeastern Alberta, and primitive bony fish representing bowfin (*Melvius*, *Kindleia*), sturgeon (*Acipenser*), and garpike (*Lepisosteus*) occurring along with some more advanced forms (*Platacodon*, and in Alberta, *Paralbula*). Frogs and salamanders represent the amphibians, and a host of non-dinosaurian reptiles includes apodans



Cretaceous turtles Thescelus insiliens and Basilemys sp.

('legless lizards'), lizards, snakes, turtles, and crocodiles. The flying reptiles, or pterosaurs, are not found here, although they were certainly present, and at least two kinds including the giant *Quetzalcoatlus* have been recorded from Alberta. Cretaceous birds are just beginning to be known from Saskatchewan, and *Cimolopteryx* has been discovered in the Frenchman Valley of the southwest.

Latest Cretaceous mammals are now known from many localities, and knowledge about Saskatchewan's Cretaceous mammals is advancing quickly enough that any listing of known forms would soon be outdated. Particularly abundant are marsupials of the opossum family, and multituberculates, an extinct group of non-placental mammals that had sharp, chisel-like incisors and have often been assumed to have lived in much the same way as rodents. The placental mammals are also well represented, with very early 'insectivores' present at most localities. Some of the earliest known ancestors of the ungulates are known from southwestern Saskatchewan, and there is a possibility that the fossil records of other groups might be shown to extend downward into the Cretaceous. Current research in Saskatchewan is testing the exact stratigraphic position of the rapid radiation of mammals which occurred in latest Cretaceous time, in relation to the coal seam that marks the Cretaceous-Tertiary boundary. We expect to shed new light on the extinctions or rapid faunal replacements that ended the Mesozoic Era, and clarify the role of the mammals, which were cat-sized or smaller until after the dinosaurs had become extinct.

Thescelosaurus neglectus, a small plant-eating dinosaur from the Frenchman Valley near Shaunavon.

Controversy abounds regarding the series of events that, by the end of the Cretaceous Period, eliminated the dinosaurs, pterosaurs, and many of the opossum-like mammals from the land, but also caused extinction of stromatoporoids, ammonoids, belemnites, rudists, inoceramid clams, a great variety of microorganisms including globotruncanid foraminifers, and the seagoing reptiles, mosasaurs and plesiosaurs.

Two explanations for this rapid faunal replacement currently have major support among paleontologists and geologists. They are nearly opposite to each other, and depend partly on different sets of evidence, and partly on different interpretations of the same data.

One hypothesis, much publicized because it combines simplicity, finality, violence, and destruction, involves the impact of an extraterrestrial body with the earth's surface. The extraterrestrial object was about 10 kilometres in diameter, and may have been a meteor or even a ball of ice from the head of a comet.

On impact, the extraterrestrial object blasted out a crater and shattered. Dust from the crater and asteroid, along with soot and smoke from wildfires caused by the heat of impact, immediately rose to the outer atmosphere through a hole left by the extraterrestrial body's sudden penetration. This dust, soot, and smoke spread quickly around the globe, forming a barrier to sunlight. With the sun 'turned off' for months or even years, green plants were unable to grow (many had been destroyed by fire immediately after the impact), and ocean plankton that depended on sunlight also died back suddenly. With the conversion of solar energy to chemical energy so reduced by green plants' inability to grow, an ecological disaster resulted with all levels of the food chain severely affected. Large herbivores and carnivores (the great reptiles) were directly affected, but many other organisms suffered extinction, or at least reduction in numbers and diversity.

A large body of evidence supports at least the possibility that an extraterrestrial body collided with the earth about 65 million years ago. A layer of a rare radioactive element, iridium, of anomalously high concentration, coincides with the end of the Cretaceous Period. Iridium is far more common in the earth's mantle and in extraterrestrial objects than it is in the crust. 'Shocked' quartz grains at some localities, and ash that may have been from wildfires, are among other indications that an impact might have occurred. Moreover, most of the flowering plants that were present disappeared at the end of the Cretaceous Period, and just above the boundary the rocks contain only the spores of ferns. This 'dead zone' fits in with the impact hypothesis. Many publications, especially by Luis Alvarez and associates, have detailed this hypothesis (e.g., L.W. Alvarez et al., 1980; W. Alvarez et al., 1984).

On the other hand, dinosaur diversity had been dropping for at least five to seven million years before the end of the Mesozoic Era, and several groups of mammals diversified or appeared during the last million years of the Cretaceous Period. Despite the sudden plant turnover, animal groups had made their last appearances during the last 12 million years of the Cretaceous Period, and relatively few (including horned and armored dinosaurs) made their last appearances at the close of the Mesozoic. Other groups (e.g., turtles, champsosaurs, crocodiles) survived nearly unchanged into the Tertiary.

The same rock and fossil record is interpreted quite differently by different researchers. R.M. Sullivan (1987), for example, has studied the exact stratigraphic levels at which various marine and terrestrial reptile groups disappeared from the fossil record, and concluded that there was no mass extinction among the reptiles. D.A. Russell (1984), on the other hand, has interpreted the record as indicating an increasing diversity in families and genera of dinosaurs right up to the end of the Cretaceous Period, and considers that the fossil record demands an interpretation of catastrophic extinction.

Fortunately, the impact hypothesis and an alternative explanation have been stated in precise enough terms that they can be tested, and a great deal of research, including Saskatchewan research, is progressing in the area.

The alternative hypothesis is almost the opposite of the extraterrestrial impact idea, and involves gradual shifts in climate, and in plant and animal communities.

Soils researchers (e.g., Retallack et al., 1987) and paleobotanists (e.g., Wolfe and Upchurch, 1986) have found indications that climate was becoming much wetter toward the end of the Cretaceous Period. This increasing wetness may also be reflected by the increase in coal beds in western North America in the latest Cretaceous. Although no significant late Cretaceous coal deposits are known from Saskatchewan, we do have a seam (the Ferris, or Number 1) at the Cretaceous-Tertiary boundary as does the entire northern Plains area. Lignite is abundant in Paleocene rocks of Saskatchewan.

As vegetation grew denser, perhaps some groups including mammals were favored, and perhaps dinosaurs were not: could this explain the rise of mammals and decline of dinosaurs at the end of the Mesozoic Era? To be sure, there was a sudden turnover in the plant community at the close of the Cretaceous, but perhaps the shift in plant and animal communities had already gone too far by that time.

Gradual shifts in climate would also fit in well with Sullivan's observation of a gradual faunal replacement among the reptiles. This idea of a gradual (but perhaps rapid in geological terms) faunal replacement has led to many studies of faunal succession around the Cretaceous-Tertiary boundary. One of these studies is a co-operative venture by the Saskatchewan Museum of Natural History and University of Alberta, to see if the adaptive radiation that produced new groups of mammals really did precede the extinction of the dinosaurs.

Cenozoic Era

CHAPTER 6

Tertiary Period

Developments during the Tertiary Period are pivotal in the evolution of our modern flora and fauna, and Saskatchewan's Tertiary fossil record is by far the most extensive in Canada.

While much controversy surrounds events in the late Cretaceous Period, many students of fossil pollen and soils consider that the interior of North America had been growing wetter, and a prominent coal seam (the Ferris Seam, Number 1 Seam, 'Z' Coal, Big Seam, etc.) marks the Cretaceous-Tertiary boundary in the northern Plains. The Paleocene Epoch, the first part of the Tertiary Period, is typified by coal swamps in southern Saskatchewan, and the Ravenscrag Formation, which represents most of the Paleocene, is the source of our lignite coal. These coals are best known from the edges of the Williston Basin, but Broughton (1979) found that basin subsidence alone was not rapid enough to account for such thick coal deposits, and attributed the subsidence of the parts of southern Saskatchewan where coal swamps formed to salt collapse in the mid-Devonian Prairie Evaporite.

Paleocene plants are commonly preserved throughout southernmost Saskatchewan. Common are horsetails (*Equisetum*), ginkgo, cypress, elm, walnut, sycamore, and a small-leaved water plant (*Trapa*).

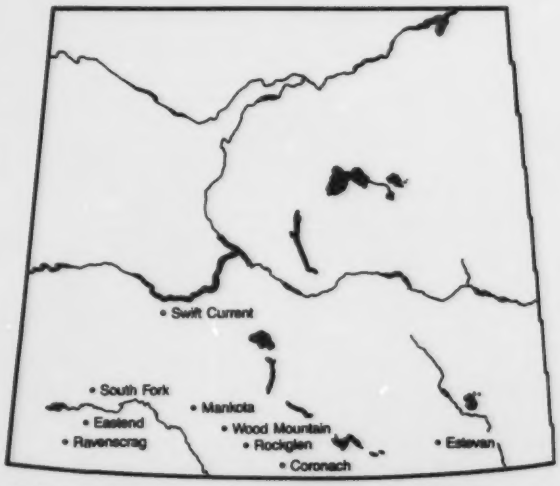
Less commonly found are the fossil vertebrates that lived in these lowland forests and cypress swamps. A varied fauna of late Paleocene age has been collected from the spoil piles at coal mines near Estevan. Only a few groups have been documented in print, but in addition to the fish, crocodiles, champsosaurs, turtles, salamanders, and lizards that had survived with few changes since the late Age of Dinosaurs lived a varied assemblage of mammals that included the large

Ptilodus kummae, a multituberculate mammal from the late Paleocene Epoch, found near Estevan. *(University of Alberta photo)*

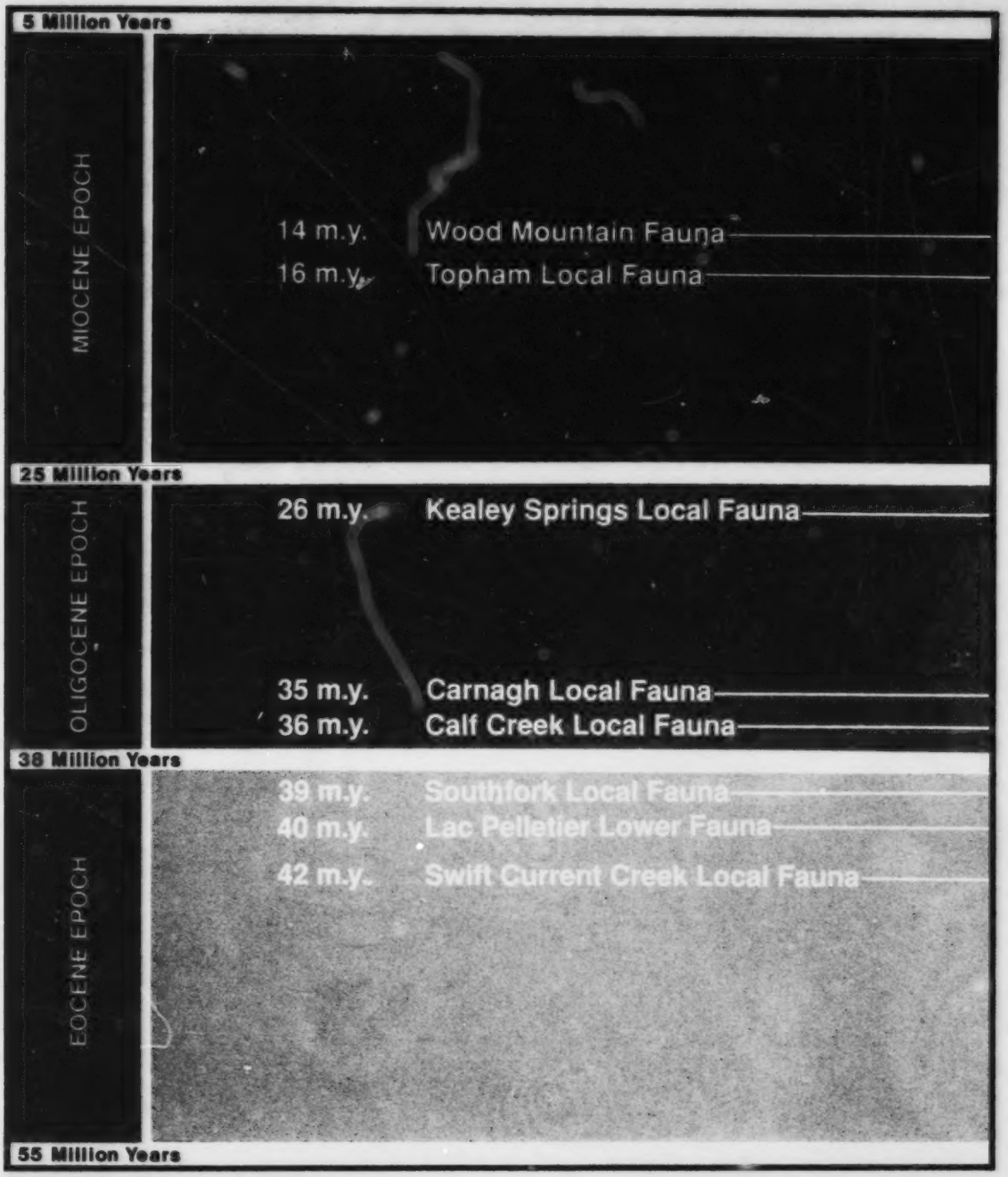
amblypod *Titanoides*, which reached nearly two and a half metres in length, a far cry from the diminutive mammals of Cretaceous time. Primates, early shrew-like mammals, ancestors of the carnivores and ungulates, opossum-like mammals, and the still-diverse multituberculates are all major parts of the fauna (Krause, 1977, 1978). One of the world's few multituberculate skeletons, that of *Ptilodus kummae*, was collected by the University of Alberta from rocks of the Ravenscrag Formation near Estevan (Jenkins and Krause, 1983).

Throughout southwestern Saskatchewan, vertebrate faunas are found in the Ravenscrag Formation. This important but under-researched formation appears to represent nearly the entire Paleocene Epoch, except the last (Clarkforkian) portion. Early Paleocene (Puercan) assemblages come from near Ravenscrag, and from Pine Cree Regional Park: both appear to be slightly older than the archetypical Puercan age fauna of New Mexico. The fauna near Ravenscrag (Johnston and Fox, 1984) preserves diverse Paleocene multituberculates, a primate (*Purgatorius*), and condylarths. It immediately overlies a latest Cretaceous fauna that contains multituberculates, marsupials, and advanced mammals including an insectivore-like form (*Procerberus*) and the condylarths *Protungulatum*, *Oxyprimus*, *Ragnarok*, and *Mimatuta*. Unfortunately some interruption in deposition occurred between the rock layers, and the coal seam that elsewhere marks the Cretaceous-Tertiary boundary does not occur there, but this pair of faunas is of great importance in understanding that part of the mammals' history, and appears to demonstrate the rapid diversification of the mammals immediately before and after the dinosaurs' demise.

Likewise, the later Paleocene fauna of Estevan documents the next step in North American mammal evolution, demonstrating the origin of most of the mammalian orders (with the rest to follow in the earliest Eocene). With further exploration, we may expect the rest of Paleocene



Major collecting areas for fossil vertebrates of the Tertiary Period.



Eocene to Miocene faunas of Saskatchewan.

time to be filled in by faunas from the Ravenscrag Formation.

The end of deposition of the Ravenscrag Formation also marks (with one outstanding exception) the end of deposition of fine-grained sediments, including floodplain and lake-bottom deposits and fine-grained channel beds. Nearly all our post-Paleocene Tertiary deposits are coarse-grained beds, typified by sands and gravels laid down in braided rivers.

After a break in deposition spanning about 12 million years, our record of late Eocene-early Oligocene faunas spans a fascinating time that saw a major climatic shift, a rapid faunal replacement (so rapid that for many years it was referred to as an extinction event), and the origin of nearly a third of the modern families of mammals. Saskatchewan faunas are the only ones known from the Great Plains that document the critical, earlier part of this climatic progression.

About 50 million years ago a worldwide series of climatic changes began, spurred by changes in the relative positions of the drifting continents. Closing of the former equatorial seaway (Tethys) between Europe and Africa, and possibly establishment of a land connection between North and South America, stopped the ancient circum-equatorial current that had collected warm water and distributed it poleward. At the same time, separation of Antarctica and South America produced a cold, circum-Antarctic current for the first time, and opening of former barriers in the South Atlantic allowed it to flow freely toward the equator. This rerouting of the earth's major ocean currents in the late Eocene Epoch, and resulting cooling of ocean waters, caused changes in air circulation patterns that produced cooler, drier, and more seasonal climates in areas away from the equator.

Meanwhile, subduction of the Farallon Plate under the western edge of North America caused folding and faulting, dominantly thrust faulting, in the northern Rocky Mountains. The northern Great Plains simply rose in elevation rather than folding, although intrusions (e.g., the Sweetgrass Hills) occurred as well. Mid-Eocene and later uplift in the western Plains has amounted to nearly 1500 metres, a change in elevation which has also influenced the local climate.

In this transition from warm, wet land lying near sea level to cool, seasonally moist high plains, Saskatchewan saw the breakup of the old wet, closed-canopy forest of the coal swamps, and the emergence of woodland savanna. A series of Saskatchewan vertebrate faunas from the Cypress Hills Formation illustrates the changes that occurred during this transition.

Coal swamps of southern Saskatchewan during the Paleocene Epoch, early Tertiary Period.

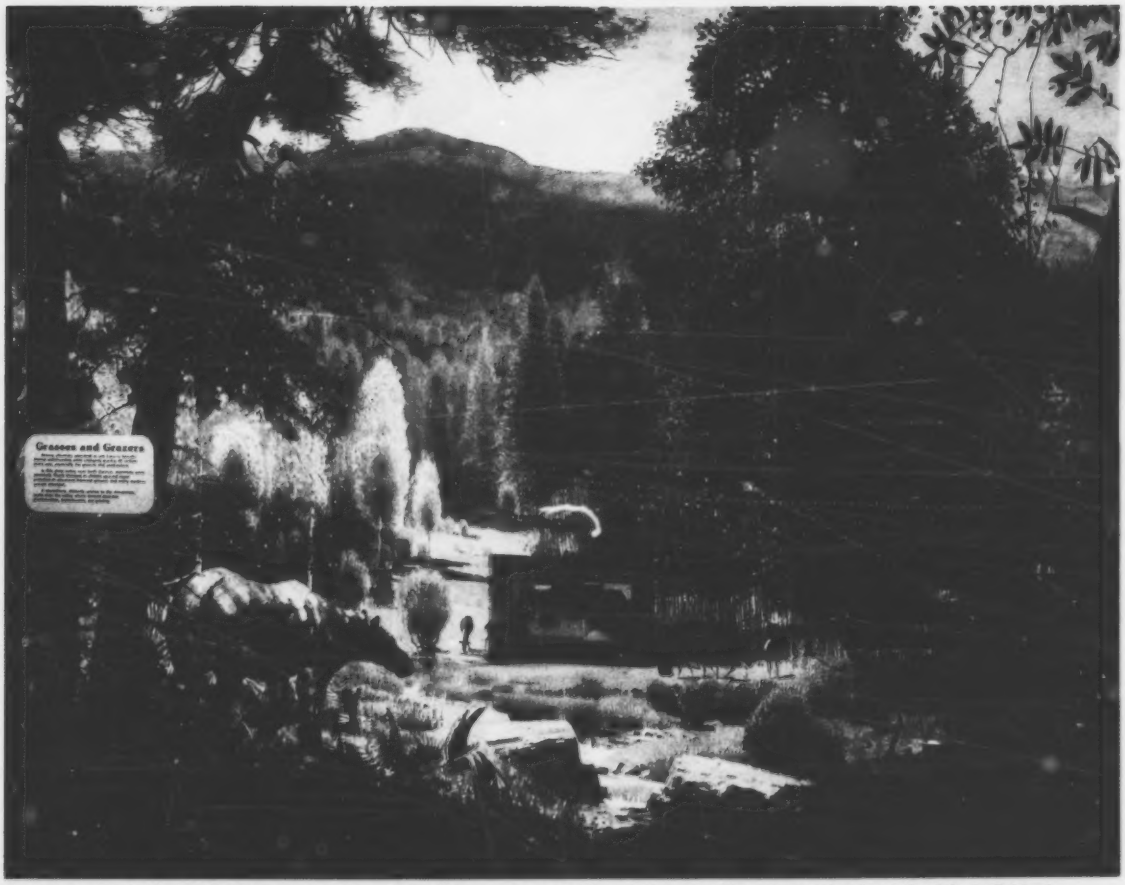
Oldest is the Swift Current Creek Local Fauna, collected from a bank above Rushlake Creek, on the Ed Wall farm southeast of Swift Current. This fauna is from the latter part of the Uintan Land Mammal Age, and is about 42 to 44 million years old. Although the fauna is of about the same age as the Myton Local Fauna of the Uinta Basin, Utah (Russell, 1965), it differs in detail, and more than half of the fossil mammals differ significantly from contemporaries from the Rocky Mountains of Utah and Wyoming (Storer, 1984).

Plants are missing from the Swift Current Creek collections, as they are so far from all Saskatchewan Eocene, Oligocene, and Miocene assemblages. Thus our detailed reconstruction of the environment is inferential. Certainly we know from floras of Wyoming that grasses had emerged as a major food supply for ungulates, and one way of analyzing the local importance of grasses is to compare the numbers of even-toed ungulates (artiodactyls) with ridged, advanced grinding teeth and the numbers of those with cusped teeth less suited for chewing of abrasive vegetation. At Swift Current there are three species (and genera) of each, hence the conclusion that while grasses had assumed some importance as a food source in the area, patches of woodland were still common or dominant. Interestingly, other faunas of the time from California, Utah, Wyoming, and west Texas indicate a greater spread of grasses and opening of the environment.

The sand and gravel beds that produce the Swift Current Creek Local Fauna are cut down into a broad, easterly-trending valley more than 60 metres deep. The deposits include large (up to 32 to 64 mm diameter) cobbles of very hard rocks (quartzite and chert), which originated at least 400 kilometres to the southwest, in western Montana. Very high seasonal flows of water must have occurred to move such large rocks. The occurrence of a large proportion (20.6 per cent) of young individuals among the mammals also indicates that deposition must have been taking place within a single season, probably spring or early summer.

Thus several independent lines of evidence give a picture of what things were like 42 to 44 million years ago near Swift Current. In a deep, broad river valley dominated by woodland but including significant grassy areas, a diverse fauna of mammals, birds, snakes, lizards, turtles, crocodiles, frogs, salamanders, and fish lived in and around a braided stream. The area was wet and rainy in spring, with torrential rains producing floods which bore heavy sediment loads. Animal remains carried with these sediments were concentrated in the river bars. During other, drier parts of the year, streamflow was greatly reduced, and growth of both the woodland canopy and the understory was lessened.

Mammals of this time included both locally-evolved forms and immigrants from Asia, and the mammalian fauna was rapidly diverging from those of the Rocky Mountains, Southern California, and west Texas. Multituberculates, marsupials, insectivores, flying lemurs, bats, primates, carnivores, condylarths, horses, rhinos, tapirs, titanotheres, cloven-hoofed grazers, rodents, and rabbits make up the mammalian assemblage. In each of these groups, fundamental changes were taking place.



A deep valley in the Swift Current area 42 to 44 million years ago. A brontothere, or titanothere, stands at the left; individuals of the protoceratid Leptoreodon marshi graze at the right. (display photo)

A very late Eocene (Duchesnean) fauna from Lac Pelletier, south of Swift Current (Storer, 1987, 1988), shows the next step in the evolution of the Great Plains environment.

In an equally seasonal climate, but on a flatter plain with lakes advancing and retreating intermittently, a tremendous variety of mammals inhabited a much more open woodland savanna than had been present in Swift Current Creek time. Cloven-hoofed grazers with curved, strong ridges on their teeth outnumber less specialized species of artiodactyls six to one, and two families of open-country rodents (pocket mice and deer mice) make their first appearances.

In the Lac Pelletier Lower Fauna we see several groups undergoing extremely rapid radiation, while 'archaic' groups are represented at least as strongly as in older faunas. The same mammalian orders are present as at Swift Current Creek, but the families and genera represent an unique mixture of typically Eocene and typically Oligocene forms. This assemblage indicates that rapid evolution accounted for the quick faunal replacement that marked the end of the Eocene; not extinction through some catastrophic event.

Meanwhile, provinciality (the tendency for different regions to be inhabited by different organisms) had become stronger. The mammals of the Lac Pelletier Lower Fauna are even more dissimilar from those of other regions than were Swift Current mammals. The Lac Pelletier assemblage shows us that the rise of new physiographic barriers and change to a more seasonal climate in the latest Eocene set off bursts of evolution independently in the various regions, and the resulting new genera and species did not spread widely until the early Oligocene, where we see a marked, sudden decrease in provinciality.

The Lac Pelletier Lower Fauna is presently being studied. Among other taxa, it contains the last varied marsupial, primate, and primitive rodent (ischyromyid) assemblages of the Great Plains, and the latest known Plains flying lemur. Because the fauna is so different from assemblages in other regions, it is difficult to correlate precisely, but we hope that paleomagnetic research (measurements of the polarity of the earth's magnetic field as indicated by the orientation of rock particles) may help to match this section with other rock sequences. A higher Lac Pelletier fauna has been sampled in bulk, but the fossils have not yet been studied.

A minor fauna northeast of Eastend, the Southfork

Local Fauna, represents the very end of the Eocene Epoch. Southfork records the arrival of entelodonts ('giant pigs') and the deer-like *Leptomeryx* in our area, but is not a varied enough assemblage to trace the progress of the entire fauna. This level is also represented in the Plains by the Yoder Local Fauna of easternmost Wyoming.

Early Oligocene (Chadronian) faunas are widely distributed, much more so than their latest Eocene forerunners. The Calf Creek Local Fauna, from northwest of Eastend, preserves about 70 species of mammals, which lived nearly 37 million years ago (Russell, 1934, 1972).

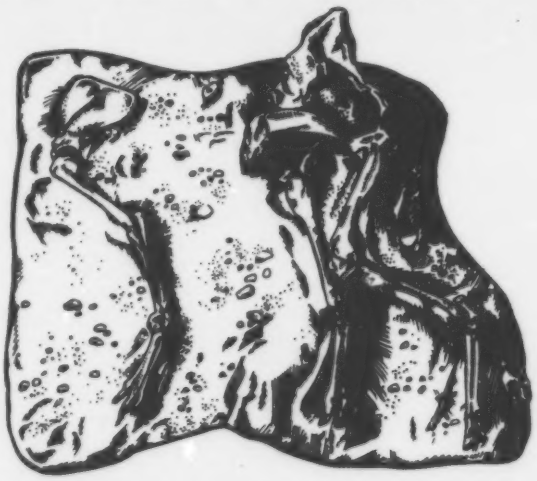
The Calf Creek Local Fauna is much more similar to assemblages of other regions than were its predecessors, reflecting the marked drop in provinciality of the early Oligocene. One of the latest known North American multituberculates, a very much reduced variety of marsupials, no flying lemurs or primates, and a very much diminished number of stem rodents (ischyromyids) are represented at Calf Creek. The presumed open-country deerlet *Leptomeryx* is extremely abundant, and so are the very large, predominantly browsing titanotheres. Horses (mostly *Mesohippus*) were diverse but not common in the fossil fauna, and a variety of other open-country grazers were present. The available evidence indicates an increasingly open environment.

Geological observations show that the early Oligocene land surface in the eastern Cypress Hills near Eastend was rather flat, with only about 15 metres relief. The seasonally-overloaded, braided streams did not cut deeply into the surface, and changed their courses frequently. Geological studies by Leckie and Cheel interpret the deposits as indicating rather dry conditions outside the rainy season, with a sparse understory in wooded areas.

This seven-to-nine-million-year sequence of faunas of the Cypress Hills Formation documents the major environmental change of the Tertiary Period. At the beginning, breakup of the old closed-canopy forest was just starting, and most of the archaic mammalian groups that had inhabited that forest still survived. By the end, significant grassy areas alternated with woodland, many modern families of mammals were present, and conditions much more similar to today's generally prevailed.

The faunal turnover represented in these assemblages was so extensive and rapid that scientists long thought that a mass extinction event had occurred near the Eocene-Oligocene boundary. An iridium anomaly, like that at the Cretaceous-Tertiary boundary (Ganapathy, 1982), occurs near the Eocene-Oligocene boundary, and it is possible that an impact of an extraterrestrial body may have taken place then, but the fossil record as it is now known indicates a burst in evolution rather than a decrease in diversity, and a gradual disappearance of archaic groups rather than a simultaneous one.

Like the late Cretaceous and Paleocene record of Saskatchewan, the fossil record of this Eocene-Oligocene transition is bound to improve dramatically. Despite current knowledge in some detail of five Eocene-Oligocene local faunas from the Cypress Hills-Swift Current plateau complex, several more scattered fossil-bearing localities are already known from public reports and reconnaissance, each bearing its own distinctive assemblage of mammals. Presumably large collections can be obtained from at least some of these sites, to fill gaps in our record, but much more intensive effort is needed. Except for a few small areas, the Cypress Hills Formation has not been searched carefully enough, and large areas are practically unexplored by paleontologists.



Front and rear limbs of an early three-toed horse, Mesohippus westoni.

The end of the early Oligocene is not documented in Saskatchewan. At that time, the titanotheres and several minor groups became extinct, in the only extinction event that has been documented for the early Tertiary. According to Wolfe (1978), average temperature dropped nearly 10°C at this time, judging from floral diversity, leaf size, and characteristics of leaf margins. It is surprising that such a change did not cause a more major extinction.

A break of nearly 19 million years follows (but may be partly filled in by new finds). The next local fauna that has been thoroughly studied is from the latter part of the early Miocene, or Hemingfordian Land Mammal Age, and comes from the Cypress Hills northwest of Eastend.

This assemblage, the Topham Local Fauna (Skwara, 1988) is found in a light-colored sand that overlies the beds that produced the Calf Creek Local Fauna. Because of overall similarity to the Split Rock Local Fauna of Wyoming,

scarcity of insectivores, pocket gophers, and beavers, abundance of pocket mice, and predominance of grazers over browsers, Skwara (1988) has interpreted the environment of the Topham Local Fauna as a pocket of arid or semi-arid grassland, even drier and more open than the usual savanna of the time.

The Topham assemblage includes both native and Old World moles and a hedgehog; pikas and an archaic lagomorph group as well as leporid rabbits; mountain beavers, squirrels, deer mice, jumping mice, eomyids, pocket mice, a pocket gopher, and two beavers among the rodents; deer-like grazers, camels, a protoceratid, a 'giant pig,' and oreodonts; both grazing and browsing horses; a dog and a weasel. The entire fauna is noticeably more modern than its Eocene-Oligocene predecessors, and suggests, even from a cursory inspection, a far more open, grassy environment.

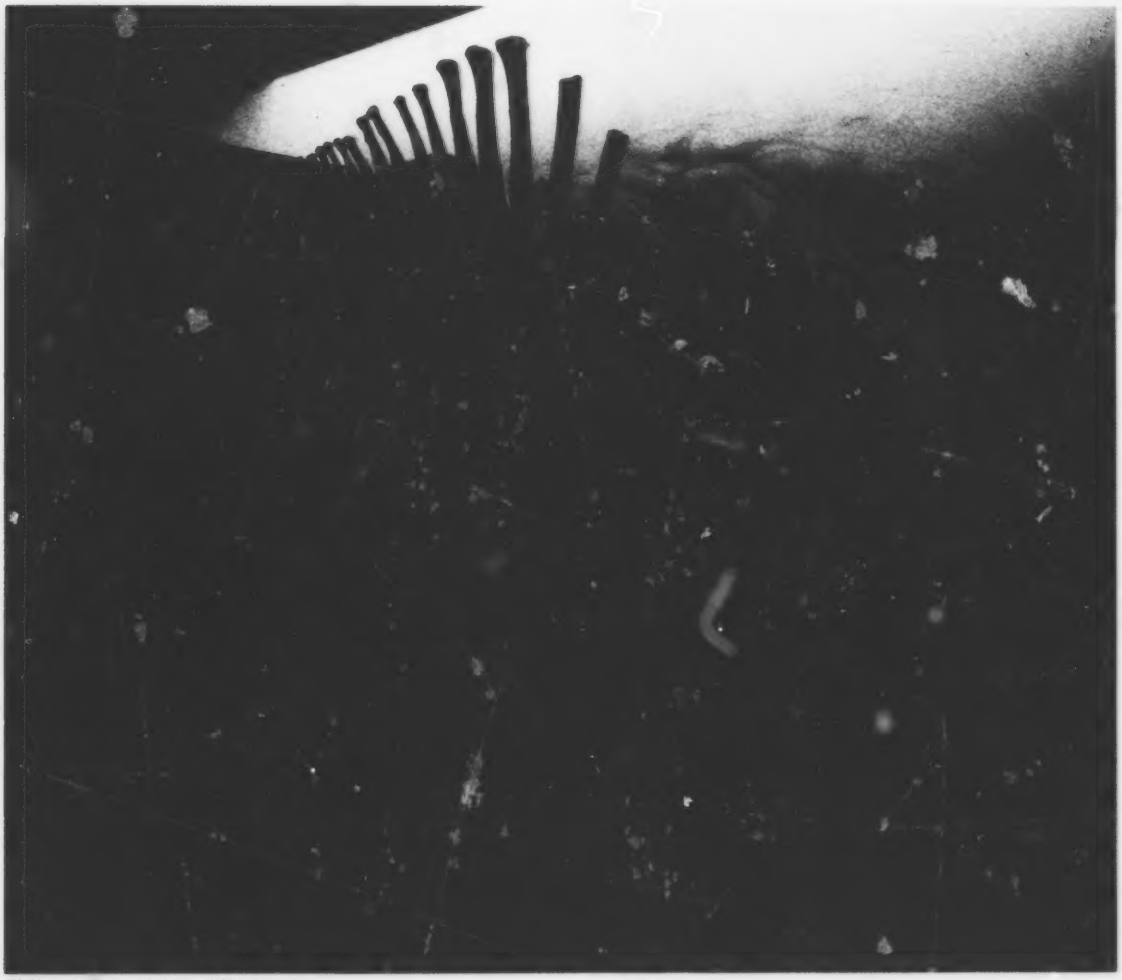
A much more extensive fauna from the middle Miocene (Barstovian) of the Wood Mountain Plateau represents the fauna of 14 million years ago (Storer, 1975). The dominant large mammals are the three-toed horse *Merychippus* and the extinct pronghorn *Merycodus*, and the small mammal assemblage is overwhelmingly dominated by pocket mice, so we may immediately conclude that the environment was dominated by grassy plain. Woodland, possibly occurring along stream banks, is also indicated by the presence of hedgehogs, moles, shrews, bassarisks, peccaries, chipmunks, flying squirrels, beavers, and a mastodont. This was probably a less dry environment than that of the preceding Topham Local Fauna, but much more open than

Giant pigs, Archaeotherium coarctatum.

Brontotheres, Megacerops.

Small deer-like grazers, Leptomeryx speciosus, and brontotheres, Megacerops.

Saber-tooth, Hoplophoneus.



Skeleton of brontothere, Megacerops.

the Oligocene landscape. As was indicated by earlier, Calf Creek deposits, the land surface was quite flat, and stream channels were not deeply incised, probably including broad flood plains.

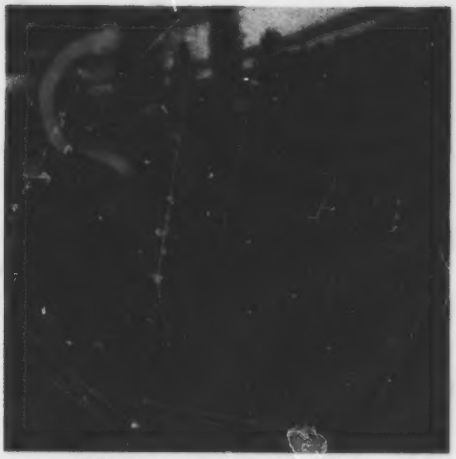
This fauna, somewhat more modern than the last, also includes cats, foxes, weasels, bear dogs, and bears; gomphotheres, another elephant-like group (Madden and Storer, 1985); browsing horses and rhinos; oreodonts, camels, and deer; horned gophers, ground squirrels, deer mice, jumping mice, and eomyids; and the archaic and modern groups of rabbits but no pikas. The fossil vertebrates are found in sand and gravel deposits from Coronach and Willow Bunch to Mankota with particular concentrations around Rockglen, Wood Mountain, and Fir Mountain, but essentially the same fauna occurs throughout, so the beds must be nearly the same age, and must have been deposited extremely rapidly. The only possible exception occurs in the Coronach area, where a few of the fossils indicate the possibility of younger beds, perhaps late Miocene (Clarendonian), like deposits located slightly farther south near Flaxville, Montana (Storer, 1969). Northern Montana deposits around Opheim, however, are Barstovian and exist on an extension of the Wood Mountain Plateau.

This succession of Eocene, Oligocene, and Miocene faunas is one that does not exist elsewhere in Canada. The only fauna comparable to any of the Saskatchewan series is found in the Hand Hills of the Drumheller area, Alberta (Storer, 1976; Burns and Young, 1988): there one finds Miocene fossil mammals that may be similar in age to the Wood Mountain Fauna, along with later Miocene and Pleistocene fossils. Several other plateaux in that province do, however, have the potential to produce Eocene and later faunas.

Apparently, transitional Eocene-Oligocene faunas also occur in the Kishenehn Formation of southeastern British Columbia (Russell, 1954). That important sequence requires intensive study.

The Tertiary transition from closed-canopy woodland with subtropical affinities to an open grassland savanna was an event that took 25 to 30 million years to take place in Saskatchewan. It was the last step in the development of our area's landscape, life, and climate before the great Ice Ages.

Aelurodon, a bone-crushing dog.



Aphelops, a heavy, short-legged rhinoceros.

Merycodus, an early member of the pronghorn family.

Merychippus, an advanced three-toed horse.

Procranioceras, a large deer-like grazer.

Rockglen area about 14 million years ago. Animals of the grassy plains gather around the stream, which is well past its peak flow.

A family of mastodonts, Zygolophodon proavus, in a small woods near Rockglen 14 million years ago. The large male is in the foreground. Zygolophodon may have been ancestral to the American mastodon of the Ice Age.

Quaternary Period

Giant sloth, Megalonyx.

Shrubox, Euceratherium.

Bone-crushing dog, Borophagus.

Imperial mammoth, Mammuthus imperator; giant sloth, Megalonyx; large horse, Equus pacificus; and white-tailed prairie dog, Cynomys leucurus.

The last major event in Saskatchewan's geological evolution was the Ice Age or Quaternary Period. At least five continental ice sheets covered the province during the last two million years, eroding older rocks and leaving behind a new mantle of deposits. Except for the Wood Mountain and Cypress Hills plateaux, which were not covered by ice because of their height, these glacial deposits make up our modern landscape.

Representing our early Pleistocene is the Wellsch Valley Local Fauna. Following an early glaciation about which little is known except that it preceded the Nebraskan ice sheet, a sequence of silts and sands formed in intermittent streams and ponds. Stalker and Churcher (1972, 1982) thought that the environment 1.8 million years ago was unusually dry, with badland topography surrounding a lake. The lake may have been a cold, proglacial lake (one that occupied the depressed area at the toe of the glacier).

Fossils from Wellsch Valley include a giant sloth, a rabbit, prairie dog, pocket gopher, voles, bog lemming, bone-crushing dog, coyote, imperial mammoth, horses, peccary, camel, and shrubox. This generally dry-country assemblage is shown in a diorama in the museum gallery. Wellsch Valley is the only known occurrence of its age in Canada.

The Wellsch Valley Local Fauna presents some problems in correlation. The composition of volcanic ash and the magnetic polarity of the sediments date the fauna near the end of the

The unique Wellsch Valley fauna, more than a million and a half years ago.

Olduvai Paleomagnetic Event. While the bone-crushing dog is more typical of Pliocene time and is an unusually late occurrence at Wellsch Valley, the mammoth is an early occurrence, dating near the time of immigration of the group into North America about 1.5 million years ago.

Next comes a nonglacial interval represented by a layer of volcanic ash near Regina. The Wascana Ash correlates with Pearlette Type O ash in Kansas, and is about 600,000 years old, or Aftonian (pre-Kansan) Interglacial. No fossils are known from this part of the section.

Saskatchewan's other vertebrate faunas represent the Sangamonian Interglacial and Wisconsinian Glacial stages. These are the last interglacial and glacial times. Earlier, Yarmouthian Interglacial faunas are well known from Medicine Hat, Alberta (Stalker and Churcher, 1982), but have not yet been found in Saskatchewan.

Faunas from Fort Qu'Appelle (Khan, 1970) and Saskatoon (SkwaraWoolf, 1980) represent the Sangamonian Interglacial of nearly 120,000 years ago. Echo Lake (Fort Qu'Appelle) fossils indicate a mixed, patchy (parkland) environment, and include badger, mammoth, horse, camel, elk-moose (*Cervalces*), giant bison, and muskox. Fish and grouse have also been reported from the deposit. Unfortunately the fauna of large mammals presents problems in both correlation and interpretation.

A much more extensive fauna from Saskatoon, the Riddell Local Fauna (SkwaraWoolf, 1980) has produced rabbits, ground squirrels, prairie dog, pocket gopher, voles, muskrat, coyote, fox, mammoth, horse, camel, deer, and pronghorn. SkwaraWoolf thought that "the landscape was dominated by open grassland with trees and shrubs occurring in low areas and along river valleys."

A great part of the Pleistocene story is the ice itself. Since about 1840, when Louis Jean Agassiz proposed a widespread continental ice sheet as the most likely explanation for the origin of surficial deposits in Europe, the concept of glaciation has become established and accepted. Yet many details remain to be studied, and some concepts are still changing.

Pleistocene glaciation of the northern hemisphere is far from unique, and ice sheets have come and gone throughout the earth's history. At various times during the Precambrian, ice sheets lay on parts of most continents. About 2100 million years ago central Canada, Utah, and parts of Australia and southern Africa were glaciated, and evidence of glaciation lies just beneath the Precambrian-Cambrian boundary in southern Africa, China, Norway, east Greenland, India, and Australia.

Other glacial episodes include the late Ordovician of North Africa, the early Carboniferous of eastern Australia, the early Permian of nearly the entire Southern Hemisphere, and the Cretaceous of eastern Australia. Pleistocene glaciation of the Northern Hemisphere is far from unique, and ice sheets have come and gone throughout the earth's history.

For glaciation to occur, it is critical for a snow field to build. If snow that falls in winter is not completely melted during the summer, thick ice gradually accumulates. When enough ice has accumulated, it may begin to spread away from the snow field, while more ice builds behind it. The ice sheet continues to advance to a point where the rate of melting equals the rate of advance.

Scientists do not agree on the causes of the cooling that allowed ice sheets to build, or the warming that stopped their accretion and allowed their melting.

Several hypotheses have been favored, including changes in the amount of energy emitted by the sun. This explanation is not capable of proof, however. Other explanations propose changes in ocean currents, and thus in distribution of temperature on the earth's surface, but unfortunately we know too few details to test these hypotheses.

It has been pointed out that sea level was relatively low during Pleistocene interglacials. Perhaps altitudinal cooling of the (relatively) high land surface was sufficient to allow additional buildup of the snow fields, and thus the onset of glaciation.

Skulls of the extinct muskox, Bootherium bombifrons; the horse, Equus scotti; and the American lion, Panthera leo atrox.

Giant bison, Bison latifrons, in the Fort Qu'Appelle area before the last glacier, about 120,000 years ago.

Another recent hypothesis concerns the positions of the rotational poles. When the poles are located near the edges of continents, movements of ocean currents appear to allow more heat exchange with the atmosphere, and make the earth's surface more uniform in temperature. If the poles are within large continental land masses and well away (more than about 800 kilometres) from the edges of the continents, the heat difference between the poles and equator is increased and the poles become cold. These conditions do not seem to apply perfectly to Pleistocene glaciations in the Northern Hemisphere, although the south pole was nearly centered in Antarctica.

Whatever the cause or causes, glaciation in the Northern Hemisphere began late in the Miocene Epoch several million years ago, and roughly two million years ago ice sheets began to extend across the North American and European continents. At least five of these glaciers extended across our province, scraping away older rocks, leaving new deposits to cover the surface, and temporarily causing cyclonic winds and tundra conditions at the face of the ice sheet. The tundra appears to have existed in a narrow strip near the ice front, and interglacials were marked by somewhat less seasonal conditions than we see today in this area, with abundant bush and shrubs in the river valleys, and forests of Manitoba maple, ash, willow, aspen, spruce, and pine alternating with grasslands. Our early Pleistocene Wellsch Valley occurrence indicates a drier than usual (and more open than usual) local environment.

The withdrawal of the last (Wisconsinian) glacier was of extreme importance in our area. Nearly all the land forms we see in Saskatchewan (except the plateaux of the southwest) result from the last glaciation. Fluting fields were cut during glacial advance, and drumlins and eskers formed under the ice, but the other features came about during glacial melting.

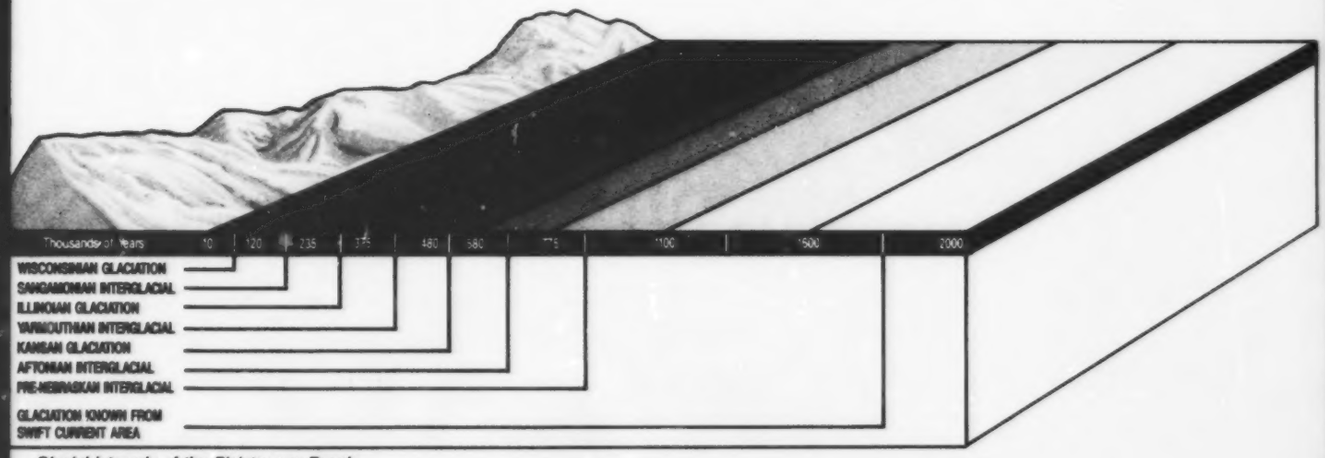
Although the advancing ice in our area may have been 1000 metres thick, during glacial retreat it was reduced to a comparatively thin 200 to 300 metres.

As glacial ice melts, the sediments that have been frozen into it are carried off the ice front in melt-water. These particles may be large rocks up to many tonnes weight, such as the glacial erratics we sometimes see on the surface. The Mistassine Rock that sat in the South Saskatchewan River valley until the creation of Lake Diefenbaker was a well known erratic. Erratics (and bedrock surfaces where they are exposed) often show grooves, or striations, caused by rubbing against other rocks as the ice advanced.

Most of the sediments are silt to cobble-sized and are more readily transported by water. Where these materials are swept rapidly away and deposited by sheets of water, they form outwash plains and till plains. If they build up at the ice front (or, in the case of valley glaciers, at the edge) they form moraines. Moraine occurs as single or multiple ridges parallel to the ice front, and as pitted terrain, the 'prairie pothole' country.

The potholes, or kettle holes, formed in moraine where blocks of ice calved off the glacier and were buried in the moraine. When the ice melted, the overlying deposits collapsed to form a depression, or kettle, surrounded by low hills, or knobs. This prairie pothole terrain covers huge areas of the Canadian Plains, and when the potholes fill with water during spring melting they provide the major habitat for waterfowl nesting.

Ponded water at the ice front formed a succession of glacial lakes. These lakes occupied the depressed area just in front of the ice, and survived until channels were available to drain the water. The largest glacial lake in our area was Lake Agassiz, which extended from Lake Superior northwestward nearly to Prince Albert, and then



Glacial intervals of the Pleistocene Epoch.

past La Ronge, from 11,000 to 10,000 years ago. The glacial lakes filled with fine sediments, and their lake basins make up the flattest areas in Saskatchewan. The organic-rich clays of the glacial lakes have formed thick, black soils that are the richest agricultural land in the province.

Where glacial meltwater ran freely and was not impounded, deep channels were cut. The Frenchman, Big Muddy, Souris, South and North Saskatchewan, Arm River, Qu'Appelle, Assiniboine, Churchill, and Clearwater valleys are all major glacial spillways, cut by meltwater flowing from the ice sheet. These valleys are now occupied by underfit streams that would be incapable of cutting their valleys by themselves, even at maximum flood stage.

Today these major glacial features, the deep valleys, glacial lake plains, moraines, and knob and kettle (prairie pothole) terrain, dominate Saskatchewan's landscape. If it had not been for the glaciers, our landscape would be more like that of Montana or North Dakota south of the Missouri River, the approximate glacial limit. There we see soils developed directly on older rocks, and much more exposure of bedrock, with the shape of the land determined directly by the pattern of weathering of ancient rock layers.

Climate change since the melting of the last glacier is the last step in Saskatchewan's geological evolution. A series of vegetational records from latest Pleistocene time to today documents the origin of today's plant communities. A major source of pre-10,000-year information is the pollen record of the prairie potholes, which developed peat bogs very much like the ones in northern Saskatchewan today. These bog occurrences reveal that immediately after deglaciation 17,000 to 10,000 years ago a black spruce-dominated forest very quickly occupied territory vacated by glacial ice, with only one site at Flin Flon showing evidence for tundra preceding the spruce zone (Ritchie, 1976). Then about 10,000 years ago the southern part of the spruce forest was replaced directly by prairie. Between 7500 and 6000 years ago climate was apparently drier than at present, and prairie extended much farther north than its modern limit. A major southward extension of boreal forest apparently took place about 3000 years ago.

Ten thousand years before the present is also the approximate date of the 'megafaunal extinction' of North America. Giant sloths, glyptodonts, American lion, cheetah, saber-toothed cat, several native horses, tapirs, camels, mastodon, mammoth, and many other mammals became extinct in North America. Some other mammals survived but became extinct later: for example, the 'Mexican half-ass' *Equus conversidens* survived to about 8000 years ago, then became extinct.

Whether the extinction of large mammals was caused by climatic change or human hunters is hotly debated. Humans had arrived in the interior of North America by about 14,000 years ago, and presumably spread quickly throughout the continent. It is uncertain whether early hunters could have killed enough animals to cause extinction, but mammoth kill sites are known from the earlier part of the archaeological record in the western United States, and there is no question that hunters had a profound impact on populations.

In comparing these glacial and postglacial climates with what we see today, we must remember the pervasive influence of human activity on the environment. There has been a historical reduction of grasslands, largely due to agricultural development rather than changing climate. Land given over to agriculture or invaded by parkland because of suppression of prairie fires no longer has the characteristics of grassland. Animal ranges too have changed dramatically: extinction of the Plains Grizzly Bear, near extirpation of both Plains and Wood Bison, and historical records of pronghorn as far north as the forks of the Saskatchewan near Prince Albert remind us of very recent changes.

Origin of the Prairies. The last series of changes leading to our present climate came during the last 15,000 years. Black Spruce forest filled our area after the melting of glacial ice. We can see remains of this forest in buried logs throughout the 'pothole' country. Grassland suddenly replaced the forest in southern Saskatchewan about 10,000 years ago. This was the origin of the modern prairie, and our familiar open spaces. Between about 7500 and 6000 years ago climate was apparently drier than it is now, and the prairie extended much farther north than its present limit. A major southward extension of boreal forest took place about 3000 years ago.

Origin of the prairie, when black spruce forest was replaced by grassland about 10000 years ago

Summary

One of the most important aims of a natural history museum is to show visitors a story that can be appreciated in terms of their own surroundings, and to inspire them to look at their environment with new insight.

We have traced the origin of Saskatchewan's land, life, and environment as the result of a series of five geological events, five ancient environments. These include plate collision creating chains of volcanic islands, and eventually a kilometre-high mountain range; shallow seas; emergence of land and dinosaurs; breakup of the ancient forest and spread of grassland; and finally the Ice Age and origin of the prairies.

It is important to know this sequence of events because of the effect they have had on our lives. The landscape we see around us is the result of these past events, especially the last glaciation which reshaped and covered the entire province except the southern plateaux. The rich soils of the plains, the river valleys, and the potholes where ducks and geese nest are a legacy of the Ice Age.

The events that formed our modern world provide a context for our mineral resources as well. Base and precious metals, uranium, potash, oil, and coal required special conditions to form, and their deposits accumulated in different environments, at different times.

Moreover, the fossils that represent our extinct life formed under special conditions. Fossils are always fascinating, not least because with skill and luck a person may find and hold an unique object that no human has ever seen before, that may date back tens or even millions of years ago. When we fit the fossils into the original record, we gain new insight into our ancient environments.

Because our fossils and mineral resources formed under unique conditions that no longer exist, we must conserve them. We must use them wisely or eventually we will do without. Our present world is the product of a long series of changes, and our knowledge of the past is only beginning to take shape. We may be confident only that change will continue.

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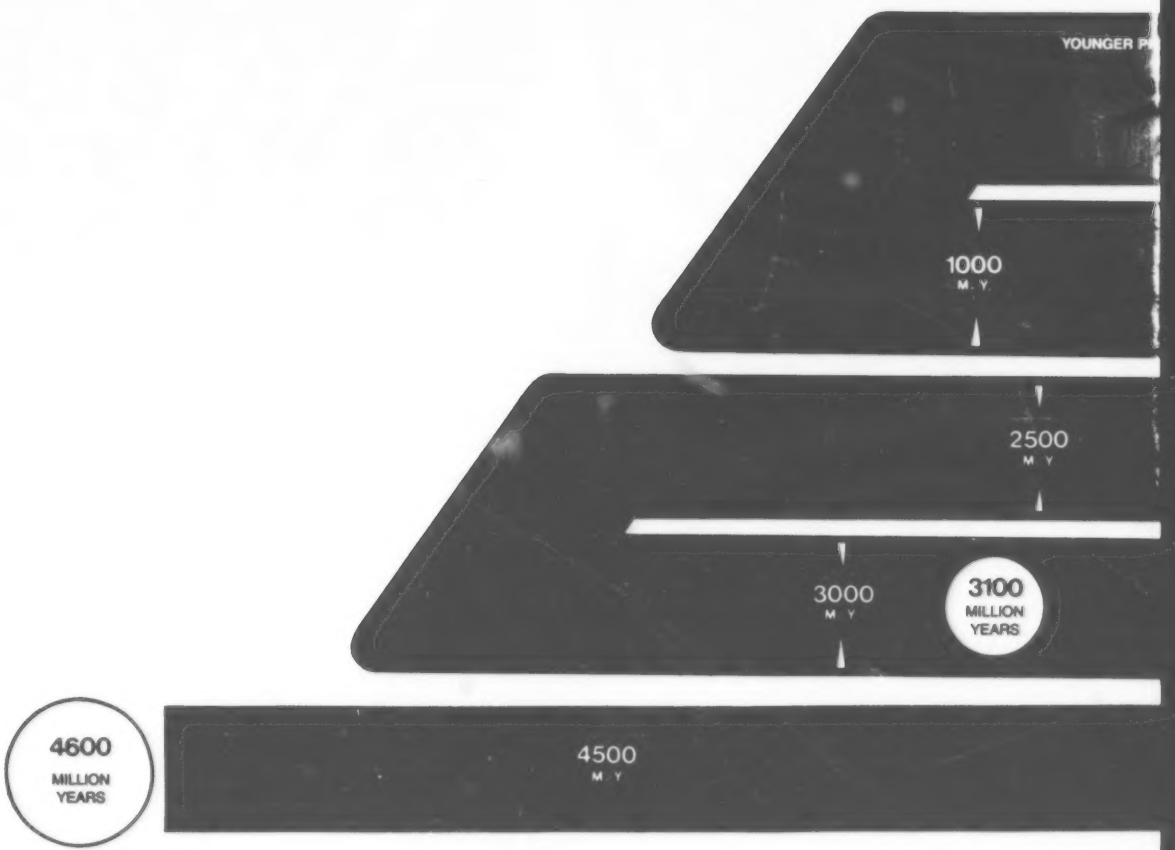
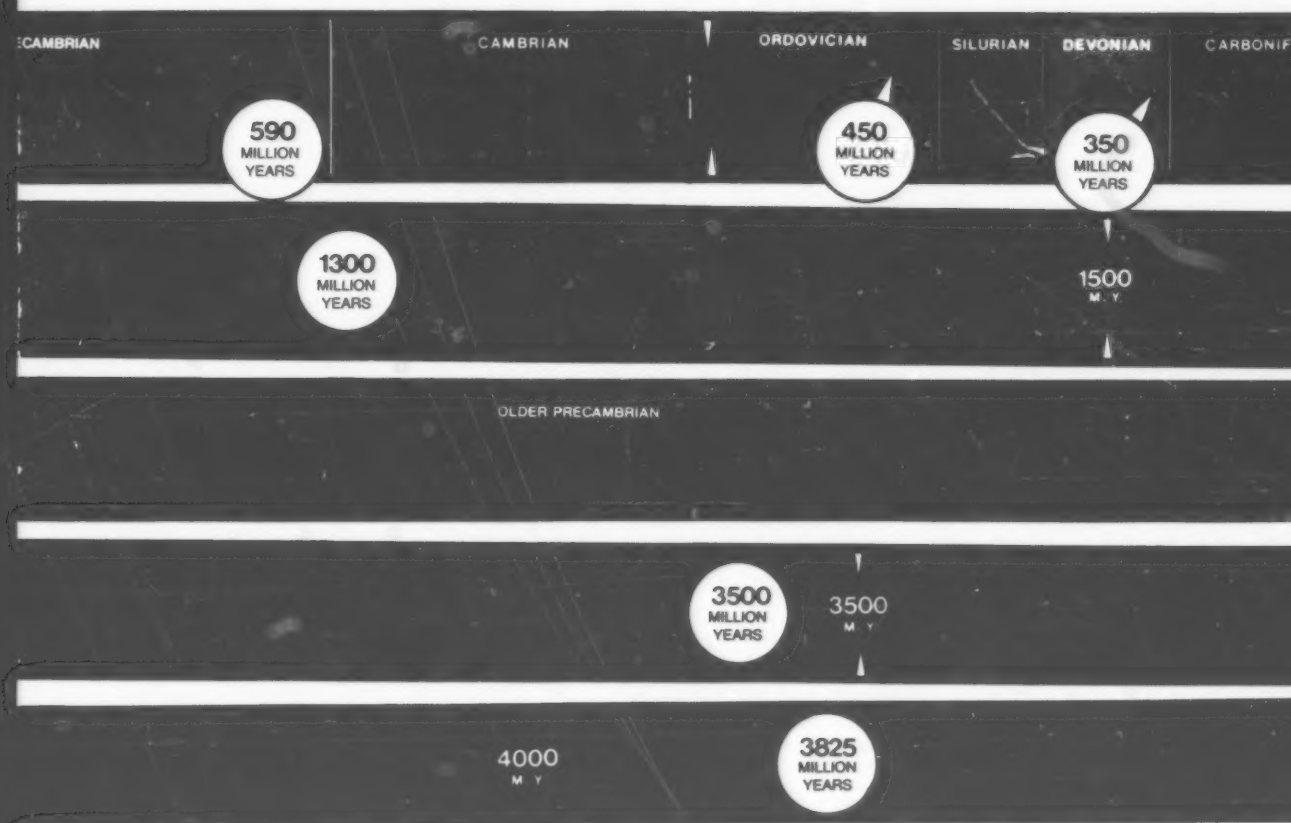
Geological Time

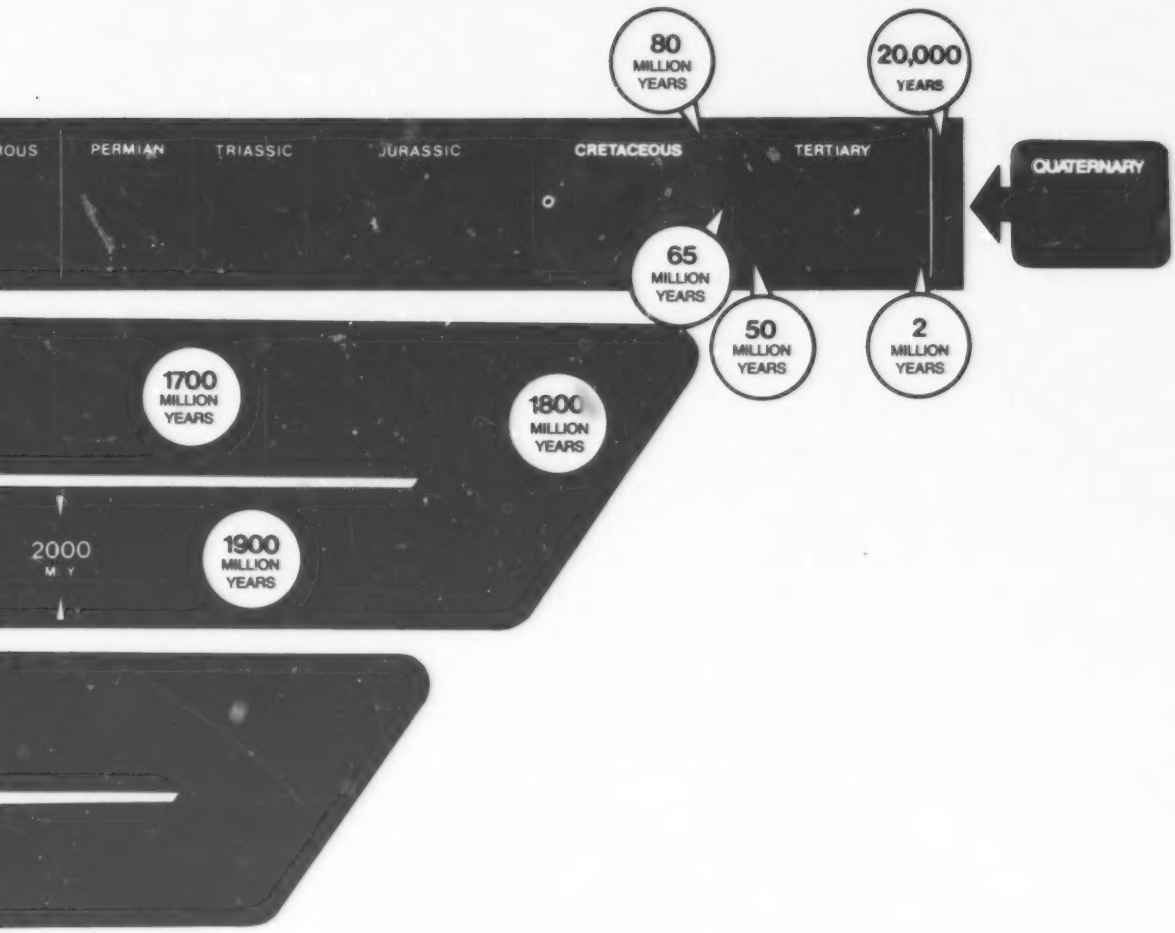
0				
		Holocene	0.01	Large mammal extinctions
	Quaternary	Epoch	0.01	Origin of prairies
0.01 m.y.				
	Period		0.02	Humans come to North America
		Pleistocene	0.05	*Bison* immigrates
		Epoch	1.5	Mammoth immigrates
2 m.y.			2	Ice Age begins
		Pliocene		
		Epoch	4	First hominids in Africa
5 m.y.				
		Miocene	14	Saskatchewan fauna, Wood Mountain
		Epoch	16	Saskatchewan fauna, Cypress Hills
25 m.y.			26	Saskatchewan fauna Cypress Hills (unstudied)
	Tertiary			
		Oligocene		
	Period	Epoch	36	Saskatchewan fauna, Cypress Hills
37 m.y.				
		Eocene	40	Saskatchewan fauna, Swift Current
			42	Saskatchewan fauna, Swift Current
		Epoch	50	Worldwide climate change, Saskatchewan plateau deposits, first grasses
			54	First horses, tapirs, rhinos
55 m.y.				
		Paleocene		
			60	Saskatchewan coal swamps, faunas at Estevan and in southwest
		Epoch		
65 m.y.			65	Extinction of dinosaurs, appearance of primates
	Cretaceous		75 to 65	Saskatchewan faunas, Killdeer and southwest
	Period		80	Saskatchewan muddy seas, mosasaur and plesiosaur
			120	First angiosperms (flowering plants)
144 m.y.				
	Jurassic		147	*Archaeopteryx*
	Period		180	Central Atlantic opens
213 m.y.			213	Extinction of many land vertebrates
	Triassic		220	First mammals, first birds(?)
			230	Rapid evolution, mammal-like reptiles
	Period		245	First dinosaurs
248 m.y.			248	Mass extinction in the oceans: 90 per cent to 96 per cent of species disappear
	Permian			
	Period			
286 m.y.				



	Carboni-	Pennsylvanian		
320 m.y.	ferous			
	Period	Mississippian	330	First reptiles
			355	First amphibians
360 m.y.			360	First gymnosperms
	Devonian		380	Saskatchewan salt, anhydrite, potash beds, first insects
	Period			
408 m.y.				



	Silurian	415	First land plants
	Period	420	First jawed fish
438 m.y.			
	Ordovician	450	Massive limestones, Tyndall Stone
	Period		
505 m.y.			
	Cambrian		
		540	First vertebrates (jawless fish)
	Period		
590 m.y.		590	First hard-shelled invertebrates
	Proterozoic	670	First complex (metazoan) organisms
	Eon	1300	Saskatchewan uranium deposits
		1700	Erosion of Saskatchewan mountains



		1800 Change from anoxygenic to oxygenic atmosphere, Saskatchewan mountain-building
		1900 First known multicellular organisms. Volcanoes in Saskatchewan, copper, zinc, gold deposits
2500 m.y.		
	Archean	3100 Oldest known Saskatchewan rocks
		3500 Oldest known fossils on earth (algae and bacteria)
	Eon	3825 Oldest known rocks on earth
4600 m.y.		4600 Accretion of earth and moon